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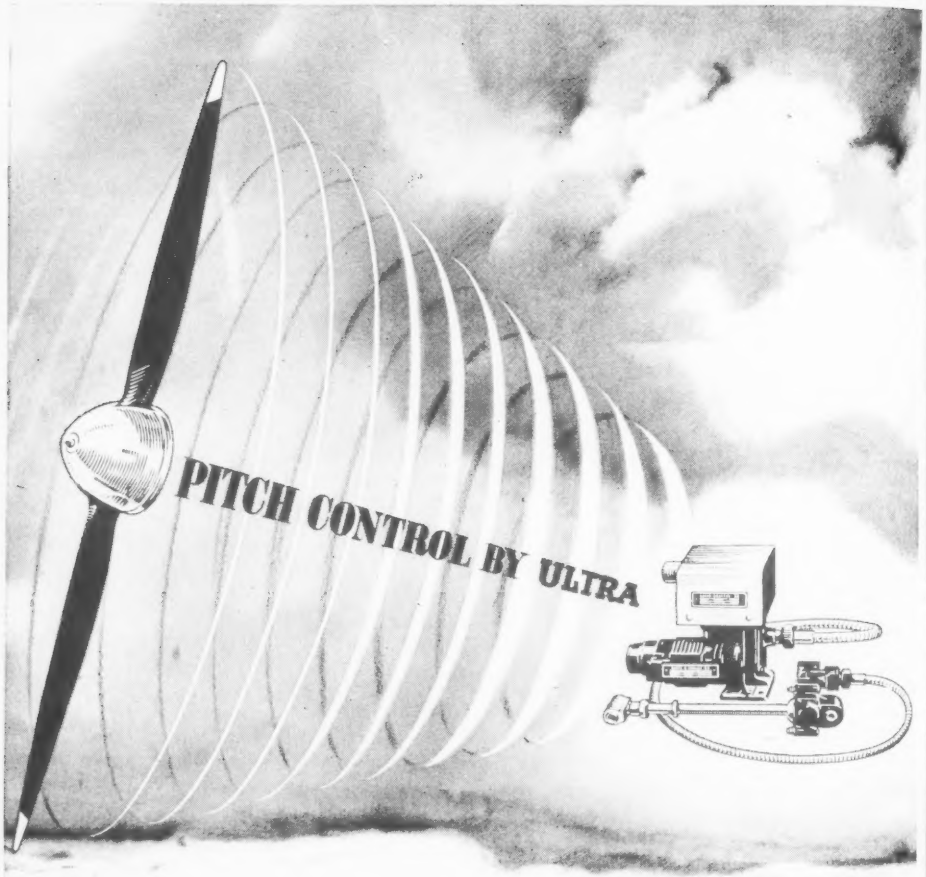

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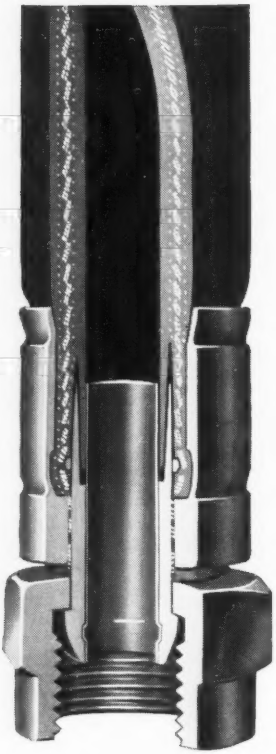

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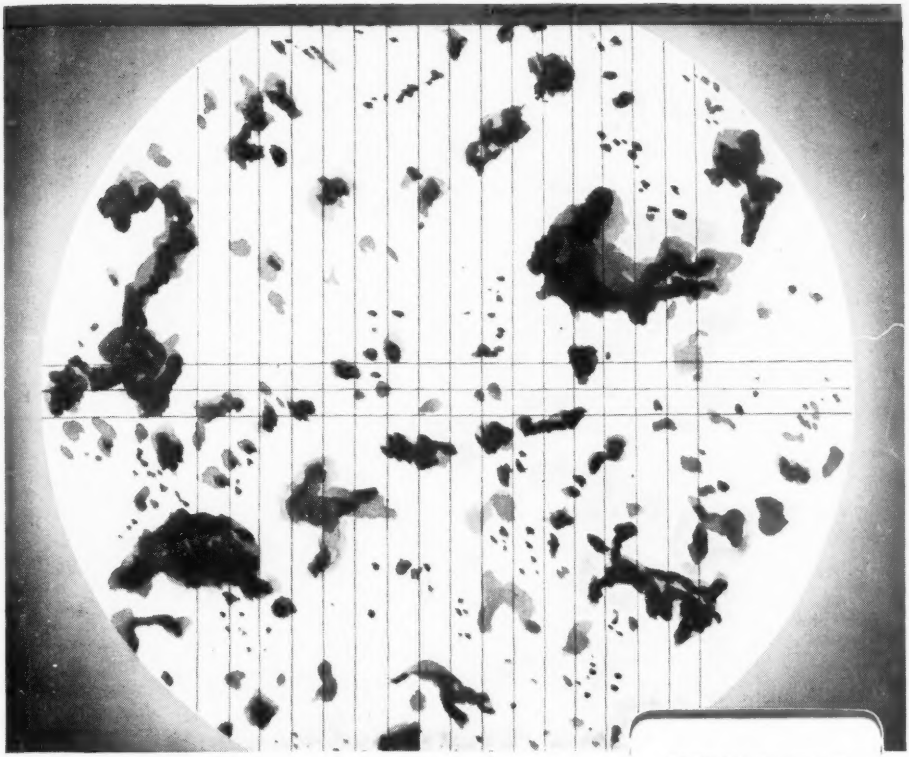

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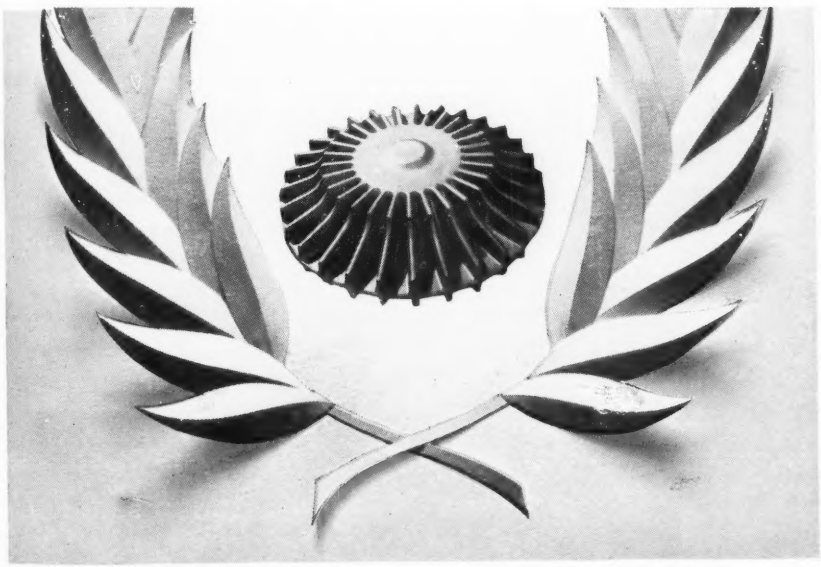

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THE ROYAL AERONAUTICAL SOCIETY

The 696th Lecture read before the Society

A CRITICAL REVIEW OF GERMAN RESEARCH ON HIGH-SPEED AIRFLOW

by

R. SMELT, M.A., A.F.R.Ae.S.

Mr. Smelt obtained his degree in Mathematics at Cambridge in 1935 and joined the Royal Aircraft Establishment in the Aerodynamics Department, working in the Wind Tunnels on general aerodynamic experiment and theory. In 1942 he became head of the Flight Section engaged in flight testing jet propulsion aircraft, investigating flight at speeds near the speed of sound and other research problems. In 1946 he became head of the Gas Dynamics Department, engaged in research and development of power units, particularly for very high speed. He is an Associate Fellow of the Society.

A MEETING of the Society was held in the lecture hall of the Institution of Civil Engineers, Great George Street, Westminster, London, S.W.1, on Wednesday, 9th October, 1946, at which a paper entitled "A Critical Review of German Research on High-Speed Airflow," by Mr. R. Smelt, M.A., A.F.R.Ae.S., was read and discussed. Sir Ben Lockspeiser, F.R.Ae.S., was in the Chair.

The Chairman: About a month after the Allied Armies had begun to roll over Germany, he had received a telephone message to the effect that the army had discovered some wind tunnels in a large forest and he was asked to go to Germany to find out what it was all about. He went, with two or three others, and was amazed to find, completely camouflaged in a forest at Volkenrode, near Brunswick, the finest aeronautical establishment he had ever seen. It was so well camouflaged that when he had flown over it afterwards, he had failed to find any detail which would lead one to believe it was there.

The quality of the equipment was of a very high order. Obviously the people concerned had been to very great pains, not only with the layout of the establishment and with the provision of the required equipment, but also to ensure that the conditions of work for the scientific workers there were such as would conduce to good work.

It was clear that much had been done there, but it was rather doubtful whether that work had had much influence on Germany's waging of the war. That was not the fault of the scientists; it was the fault of the German General Staff, who had a very poor idea of the way scientists could be used in wartime.

Fortunately, that had two good results for us. In the first place, it meant that, from the point of view of waging war, German aeronautical science did not pull the weight it might have done. Secondly it meant that, although those scientists had made tests on things such as V.1 and certainly did other work which was of use for war, they had had a lot of time in which to think fundamentally about aerodynamic problems. As a result there was quite a pilgrimage after the war from this country—from the Royal Aircraft Establishment, from

the Universities and from the Industry—by people who talked to the scientists and learned much about the work they had done.

One of those who had made a visit was Mr. Smelt, who had spent a very profitable time there. He had talked with the scientists, had examined the work of the German scientists at Volkenrode and elsewhere, and had written an account of the high-speed work that was done at their establishments. He was probably better qualified than anybody else in this country to do that kind of work. In England he was in charge of experiments in a similar field, with very much less equipment than the Germans had had, and very much smaller facilities. The work which was done in England during the war on high-speed flight, a large part of it in the air, was of considerable importance, and he doubted whether sufficient credit had been given to Mr. Smelt and his fellow scientists and pilots. They had actually dived a Spitfire at Mach No. 0.92, a very creditable achievement and a fairly dangerous experiment considering that the Spitfire was designed for a very different duty.

Measurements of drag up to that Mach number were made in the air and compared with measurements in the high-speed tunnel. The results themselves, and the technique which had to be developed to obtain them, were of great value. Experiments such as these would in future become of even greater value for he believed that for such work it would be necessary to go more and more into the air.

In the course of these experiments there was a very happy relationship between the scientists and the pilots; without it nothing could have been achieved. There was a story —which was probably true—of a pilot who went up to make a test at the highest Mach number and who was told by Mr. Smelt that when he dived at that Mach number he would not be able to pull out, but if he had patience he would come to a Mach number at which he could pull out. The pilot did so and found that everything happened as predicted. It was an encouraging state of affairs that pilots were prepared to risk their lives on the word of scientists. It was not a thing he would like to push too far; but the story illustrated the relationship between the pilots and the scientific staff, which alone had made experiments possible in that difficult and dangerous field.

Mr. Smelt presented his paper.

1. INTRODUCTION

Even before 1939 the problems of high-speed flow were receiving a great deal of attention in the German aeronautical world. Their leading aerodynamicists, Prandtl, Busemann and Schlichting among others, had contributed largely to the theory of compressible fluid flow, and basic experimental research in the high-speed field had begun both at Aachen and at Göttingen. The activity in Germany in this particular field before the war was, in fact, much greater than in Britain, where Mr. Lock and his co-workers at the National Physical Laboratory carried practically the entire responsibility for such work.

The great increase in aircraft speeds during the war, and in particular the arrival of jet propulsion, completely changed our attitude to the subject in Britain. What had been an absorbing fundamental study became, quite suddenly, an important operational problem, looming large in every new fighter design. It is true to say that from 1943 to the present day, the problems of subsonic compressible flow have headed the aerodynamicist's list. Indications were not lacking that the Germans, also faced with high fighter speeds and jet propulsion, had intensified their own work on compressibility phenomena. Indeed, these indications were not wholly documentary in character; the

arrival of V2 in England was evidence of a considerable background of knowledge of supersonic aerodynamics.

When in 1944 the armies began to push into Germany, arrangements were made to collect, as quickly as possible, German work on the subject. To this end, Mr. McKinnon Wood and myself paid a rather unsuccessful visit to Aachen in October 1944; and this first visit has been followed by innumerable others, by many investigators, as German research centres were overrun. The high-lights of the German research work were known fairly completely to us by about August 1945, although the collection of details was then barely started, and, in fact, is still not fully complete.

In this short paper, it is impossible to give anything like a full description of the German research work, the product of many scientists working steadily through the war years. Rather than attempt this, it is preferable to concentrate on the high-lights; on those aspects of German work which have given strong confirmation of our own ideas or have modified greatly our line of attack on the compressibility problem.

2. GERMAN RESEARCH CENTRES

By far the greatest contribution to high-speed research was made by the Deutsche Versuchsanstalt fur Luftfahrtforschung (D.V.L.) in Berlin and the twin organisations of K.W.I.* and A.V.A.* at Göttingen. Both these centres, and many of their personalities, were well known to us before the war. A third station, the Luftfahrtforschungsanstalt Herman Goering (L.F.A.) near Brunswick, was found to be just as lavish in equipment. Conceived in 1935, and elaborately camouflaged, it had not really started experimental work until about 1942; and the inevitable delay, due largely to development of techniques, resulted in its contribution being rather smaller than that of the two older institutions.

A fourth research station for the German Air Ministry, apparently intended to be even larger than any of the others, was in process of being erected near Munich, with an outstation at St. Otztal in the Tyrol. Although this station is of considerable interest to designers of aerodynamic research equipment, as indicating the latest ideas of the Germans on the subject of high-speed wind tunnel design, it produced no experimental data before the end of the war.

The work at Aachen was seriously disrupted by its proximity to the frontier, necessitating evacuation both at the beginning and at the end of the war. Thus contrary to expectation, it produced nothing of any great value on high-speed flow, apart from a very excellent book by Professor Sauer,† summarising the present position of theories of compressible fluid flow in Germany. The existence of this book makes it unnecessary to give more than a few brief comments on German theoretical work in the present paper.

It is impossible to omit the work on supersonic flow done by the Peenemunde group (evacuated to Kochel) during the design of V-weapons, although this work was directed by the Army and not the Air Ministry. The research done by this group, particularly in its later stages, has considerable importance in its application to high-speed aircraft of the future.

3. RESEARCH EQUIPMENT — HIGH-SPEED WIND TUNNELS

3.1. *General*

It is not proposed to give here a detailed description of the equipment for high-speed flow research at all these experimental establishments, as this formed the major proportion of the equipment at each establishment. Table 1 summarises the characteristics of the high-speed wind tunnels in use or being built, and Figures 1-6 show some of the more important.

* K.W.I. = Kaiser Wilhelm Institut.
A.V.A. = Aerodynamische Versuchsanstalt.

† Theoretische Einführung in die Gasdynamik (Dr. Robert Sauer) 1943.

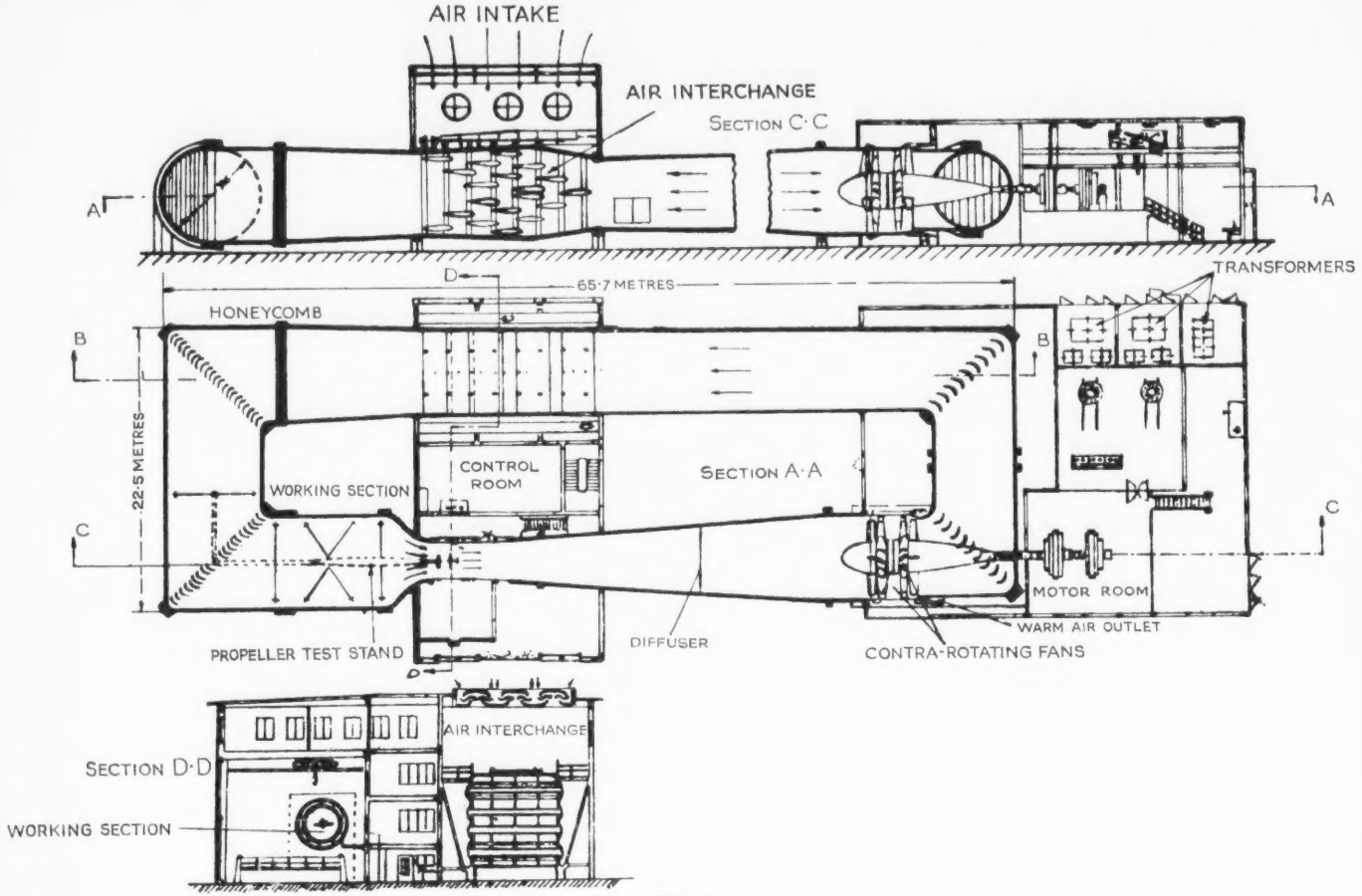


Fig. 1.
D.V.L high-speed wind tunnel.

Fig. 1.
D.V.L high-speed wind tunnel.

TABLE I. CHARACTERISTICS OF SOME GERMAN HIGH-SPEED WIND TUNNELS

Location	Date of first running	Dimensions	Open or Closed	Maximum Mach Number	Working section stagnation pressure (Approx.) (atmosphere)	Available Power (H.P.)	Remarks
D.V.L., Berlin	1939	Circular, 9 ft. dia.	Closed	1.0*	1.0	17,500	See Fig. 1
A.V.A., Göttingen	1941	Square, 2.6 x 2.6 ft.	Closed	1.0*	1.0	Injector	Operated by steam injector
	1939	Circular, 8.5 ins. dia.	Open	1.0*	1.0	Intermittent	
	Pre-war	Rectangular 4.3 x 5.1 in.	Open	3.0	1.0	,, ,,	
	1945	Square, 8.5 x 8.5 in.	Open	3.0	1.0	,, ,,	
L.F.A., Volkenrode	1942	Circular, 9 ft. dia.	Closed	1.0*	1.0	16,000	
	1940	Square, 16 x 16 in.	Closed	3	1.0	Intermittent	No drier for entering air (Fig. 3)
	1940	Square, 10 x 10 in.	Closed	4	0.08 to 1.0	1,350	(Fig. 3)
	1943	Circular, 40 in. dia.	Open	1.05	0.1 to 1.0	16,000	Operated by centrifugal compressor (Fig. 4, 5)
	1945	Square, 37 x 37 in.	Closed	1.8	0.1 to 1.0	16,000	
Munich	Being built	Square, 9 ft., rounded corners	Closed	1.0*	0.1 to 1.0	16,000	Flexible walls
St. Otztal	Being built (started 1942)	Circular, 26 ft. dia.	Closed	1.0*	1.0	100,000	Interchangeable working sections for aircraft and power plant tests. Operated by water turbines (Fig. 2)
Kochel	1940	Square, 16 x 16 in.	Open	4.4	1.0	Intermittent	Two of these were in use (Fig. 6, 7)
	1940	Square, 7 x 7 in.	Half open	3.3	1.0	1,100	
	Construction started	Square, 40 x 40 in.	Open	10	——	80,000	

* A maximum Mach number of 1.0 indicates that sufficient power is available to reach choking speeds with a model in position. The maximum Mach number at which significant results can be obtained with a typical model is then about 0.85.

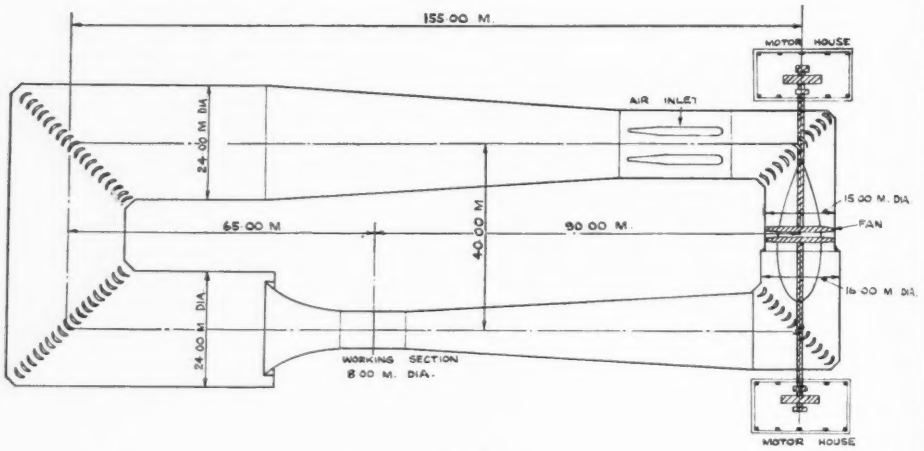


Fig. 2.
8m. high-speed wind tunnel.
Munich.

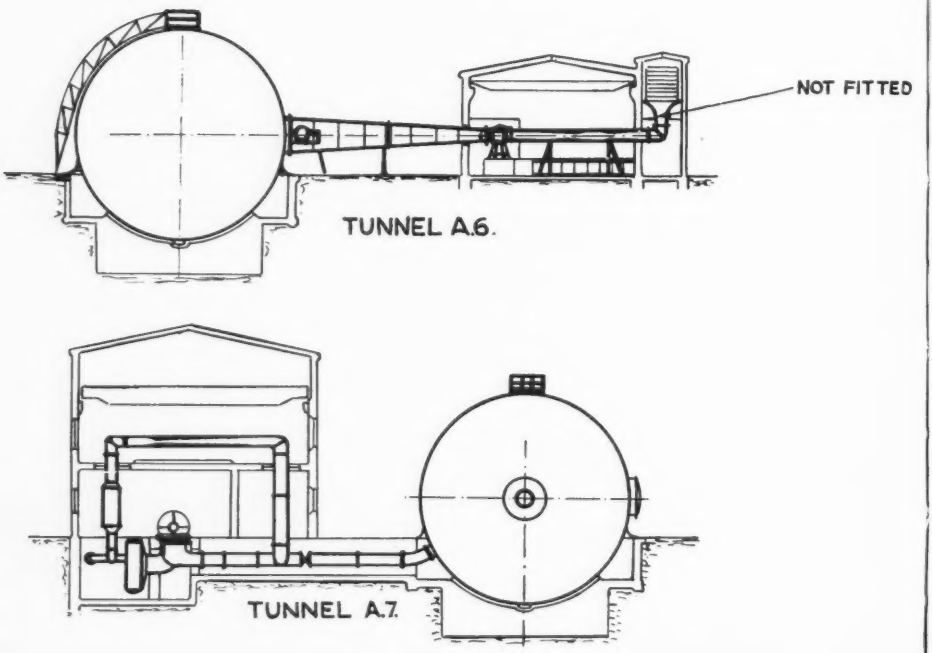


Fig. 3.
Supersonic wind tunnels, A.6/7.
L.F.A., Brunswick.

The lavishness of this equipment, and the extremely large scale of the German effort, is brought out very clearly in Table I. In both the number of tunnels, and power of each individual tunnel, the figures are considerably in excess of corresponding British ones during the war years, although this will be changed when the National Establishment at Bedford comes into operation. The 100,000 h.p. wind tunnel at St. Otztal, which was about half completed at the end of the war, was intended for tests on both the aircraft and the power unit. It is interesting in showing that Germany had recognised that the aircraft of the future would demand test and research equipment on a far greater scale of power than in the past.

In contrast with the imposing array of high-speed wind tunnels, the ridiculously small amount of German flight research at high-speeds is noteworthy. Only the D.V.L. did a moderate amount of flight work; indeed, of the newer establishments at Brunswick and Munich, the L.F.A. had only an inadequate grass aerodrome used primarily by visiting officials, and there was no mention of an aerodrome to be used by the Munich station. It might be argued that the German large high-speed tunnels approached much more nearly the full-scale conditions than our own tunnels — their 2.8 metre tunnels gave a Reynolds number of about 7 millions at high Mach number, in contrast to our 1 to 2 millions, and typical flight Reynolds numbers on high-speed fighters vary from about 10 millions at high altitude to 40 millions near the ground. Nevertheless, uncertainties in the correction for tunnel wall constraints near the speed of sound, and in the effects of wind tunnel turbulence on shock formations, make it imperative to have continual checks with the behaviour of aircraft in free flight. One or two flight experiments were made by the D.V.L. with this object, but on the whole the inadequacy of the flight work in contrast to the wind tunnel effort constituted a very weak link in the German research plan.

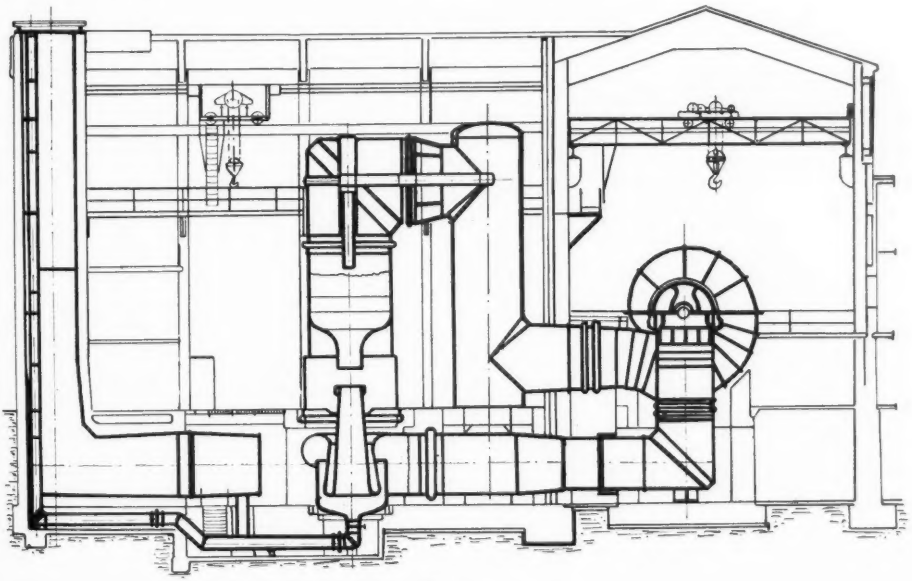


Fig. 4.
Transonic wind tunnel, A.9a.
L.F.A., Brunswick.

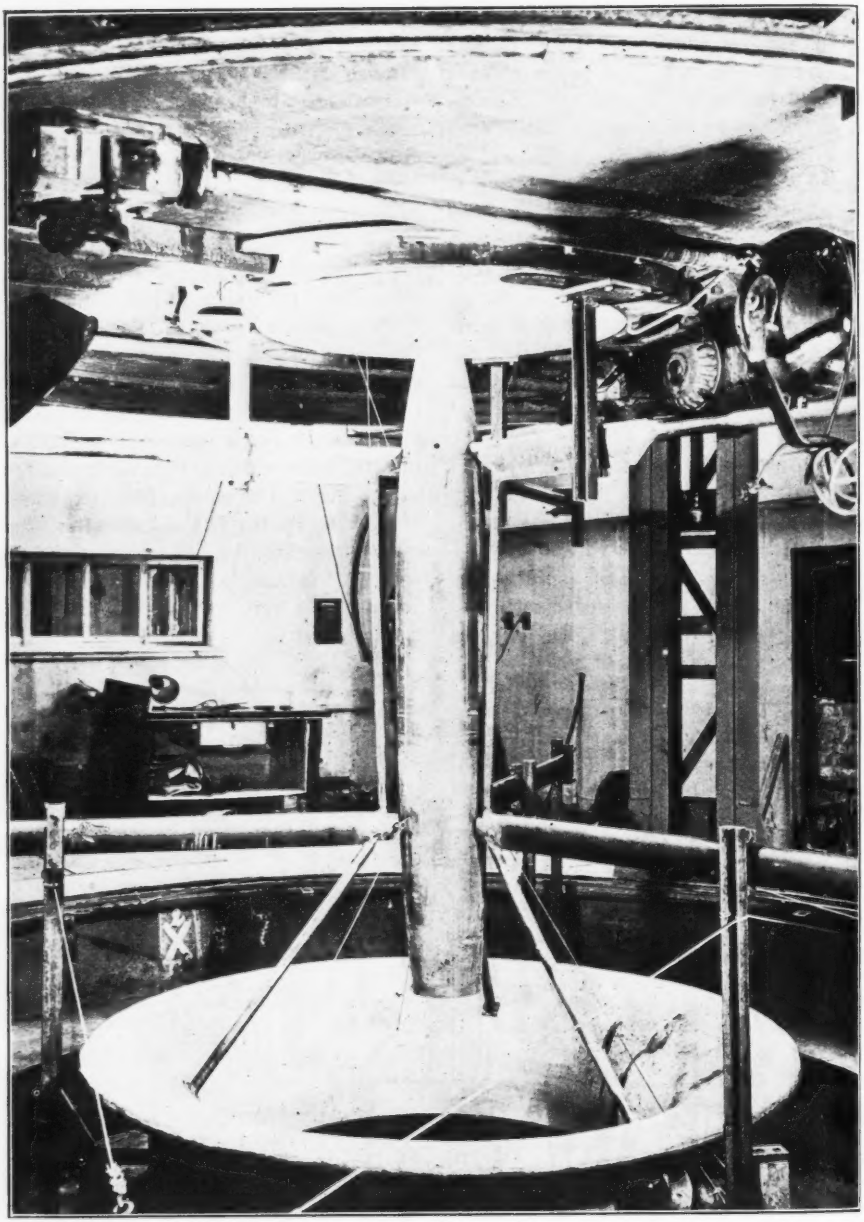


Fig. 5.
Working section of wind tunnel, A.9a, testing ram-jet model.

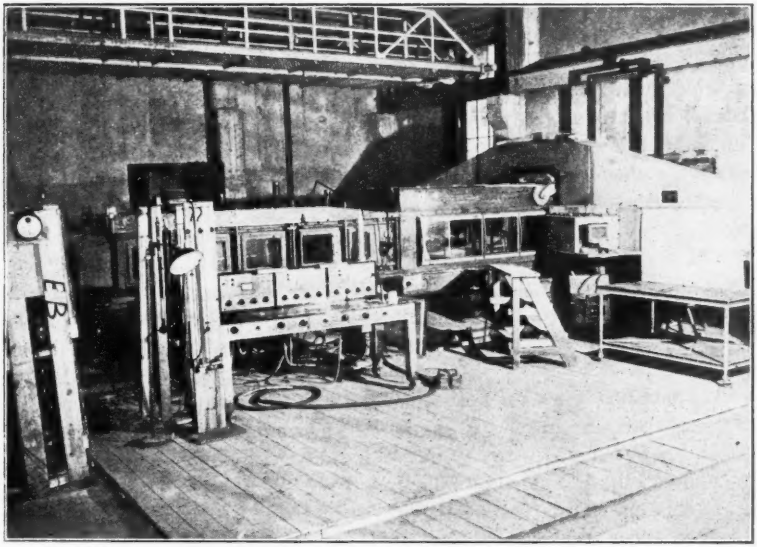


Fig. 6.
40 x 40 cm. tunnel.

3.2. *Design of high-speed subsonic wind tunnels*

The German subsonic tunnels have a few noteworthy features. They are in general very efficient; this is achieved by making a careful and long expansion from the end of the working section to the first corner. As an example, the large St. Otztal tunnel was designed to have a power factor (kinetic energy in working section/power input) of 9, whereas 3 or 4 is more usual in England; this is achieved by a very gradual expansion ($3\frac{1}{2}°$ semi-angle) between the working section and the first corner, with an area ratio of 1 to 4. In consequence, the tunnel is of prodigious length, nearly 600 ft., and the cost is high.

Like ourselves, the Germans were exercised very greatly by the problem of wind tunnel wall corrections at high Mach number. They had arrived at the same position as us, at the end of the war, in applying theoretical corrections based on linear compressible flow theory with allowance for the wake behind the model. They had come to the conclusion that the corrections to open jet tunnel results near the speed of sound were only about one-third of those for a closed tunnel. In spite of this, it will be noticed in Table I that the preference was for closed tunnels for subsonic work. Open jet tunnels require much greater power for their operation than closed tunnels of the same size, and it is likely that from the point of view of size of model which can be tested with reasonable corrections with a given tunnel power, there is little to choose between the two types of working section.

In England, the National Physical Laboratory has examined the possibility of using flexible walls in high-speed subsonic tunnels, with the idea that by setting the walls along a streamline of the unconstricted flow around the model—a "two-dimensional" model—the wind tunnel corrections are eliminated. This streamline is difficult to find, but can be obtained roughly as the profile half-way between the straight wall and that giving constant pressure. The new German 9 ft. wind tunnel at Munich was

fitted with flexible walls of this type, presenting quite a serious mechanical problem on so large a tunnel. Although the possibility of modifying wind tunnel corrections in this way had been borne in mind, the main object in the Munich tunnel was rather to control the position of the shock-wave to a point in the tunnel well downstream of the model, by introducing a throat there. In this way, speeds much nearer the speed of sound at the model were anticipated, and it was further claimed that the fixed throat resulted in much steadier flow conditions around the model at high Mach numbers.

Some very interesting work on the effect of Reynolds number on flow with shock around an aerofoil was done by Dr. Göthert in the 9 ft. tunnel of the D.V.L. By making tests with aerofoils of chords varying from 35 cm. to 8 cm., and also altering the cross-section of the tunnel with false walls, he found that the pressure distribution in the region of the shock-wave on the aerofoil was much changed with Reynolds number. The pressure gradients near the shock became greater as Reynolds number increased, finally settling down to a very steep gradient, more or less independent of Reynolds number, above about 5 or 6 millions Reynolds number. He was thus led to define a "critical" Reynolds number above which tests must be made to be applicable to flight conditions, and most of his subsequent work was, in fact, carried out at Reynolds numbers higher than 6 millions. It is difficult to assess whether this figure has any general significance—it is not present British practice to test at so high a Reynolds number; but critical values obtained experimentally in this manner have a distressing habit of increasing steadily with time.

3.3. *Supersonic wind tunnels*

There is little to be said on the new German supersonic wind tunnels. Almost without exception they were intermittently operated by evacuating a container, usually spherical (see Fig. 3), and drawing in air

Fig. 7.
Entry cones of the two 40 x 40 cm. tunnels.
(The right-hand one in the photograph has a drier installed).

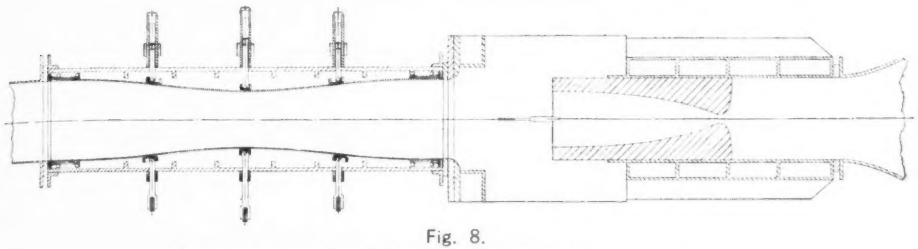


Fig. 8.
Supersonic tunnel at Kochel showing adjustable second throat.

from the atmosphere through the working section. Evacuating plant of sufficient power to exhaust the reservoir in a few minutes was used, and occasionally—at L.F.A. and Kochel — this was used to operate continuously a smaller supersonic tunnel. There was a definite bias in favour of the open jet wind tunnel.

The most interesting innovation was that of a second throat following the working section, made variable in area and quickly operable by a series of screw jacks operating on flexible walls (Fig. 8). In the closed supersonic tunnels its aim was to improve the efficiency of the tunnel after starting, by diffusing to a Mach number not greatly in excess of unity before the final shock-wave in the tunnel. In the open jet tunnel it had the more important duty of altering the static pressure in the jet to conform with the pressure outside the jet, thereby avoiding the formation of large amplitude pressure waves from the nozzle boundaries.

3.4. *Humidity effects in high-speed wind tunnels*

Work in the Aachen supersonic tunnel before the war, largely by Dr. Hermann, had demonstrated clearly the possibility of spurious condensation shocks in the flow around an aerofoil at high speeds if the relative humidity of the air were sufficiently high. It was decided that effects of this sort could not be ignored even in the subsonic tunnels using interchange of atmospheric air for cooling purposes; and in the intermittent supersonic tunnels drawing in wholly atmospheric air, very misleading condensation effects were inevitable unless the air was thoroughly dried.

In general, the solution of the problem in the subsonic tunnels was found by allowing the tunnel to heat up when running to about 40° C. above the atmospheric temperature. In the supersonic tunnels the air was drawn in through a large silica-gel drier (Fig. 7)

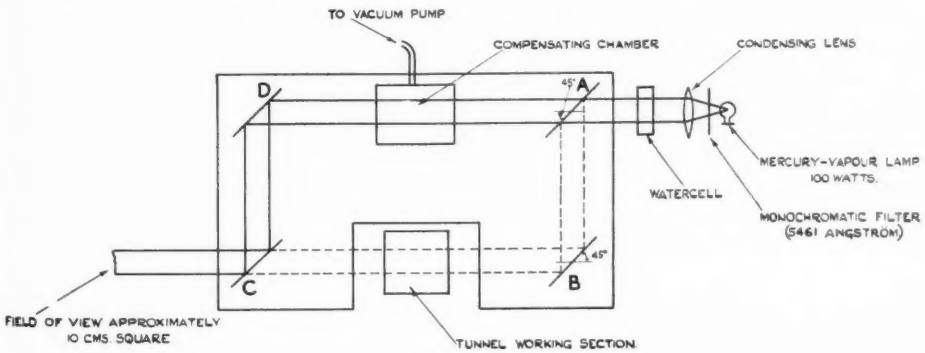


Fig. 9.
Sketch of interferometer layout.

which needed to be re-conditioned after a time by passing hot air through it.

The difference in treatment of the problem at subsonic and supersonic speeds has resulted in two different ways of specifying the permissible degree of humidity. One, resulting from some theoretical work of Oswatitsch, specifies that the dewpoint shall not be more than 50° C. above the minimum temperature in the flow, a further supersaturation resulting in a condensation shock. Another criterion used at Kochel, and more suitable for use with silica-gel driers, specifies the maximum water content of the air—a figure of 0.5 gm. per kilogram of air was frequently used. No attempt was made by the Germans to correlate these criteria, and there is no conclusive experimental evidence in favour of either. There is, in fact, room for a much greater amount of investigation of the whole problem than the Germans have given it up to the present.

3.5. *Tunnel equipment—interferometers*

The only notable feature of German high-speed tunnel equipment, apart from the general excellence of the optical apparatus, is the introduction of the Mach interferometer as a method of examining the velocity field around the model. The principle of this device is shown in Fig. 9; essentially, diffraction fringes are obtained by the interference of two light beams, one of which passes through the tunnel airstream while the other goes around it. Changes in the density of the airstream, produced by the presence of the model, result in displacement of the fringes, the displacement being proportional to the density change. A typical interference pattern, together with a simultaneous schlieren photograph, is shown in Fig. 10. If the interferometer mirrors are set exactly parallel, so that the undisturbed stream produces no interference fringes, then the disturbance due to the model in the stream produces fringes which are lines of constant density in the stream. This lends itself to direct quantitative application, provided that the pressure, and hence the density, is measured at a few reference points in the stream. The five spots on the pictures in Fig. 10 are for this purpose.

The simplest use of the interferometer is in the examination of two-dimensional flow; it has also been applied to three-dimensional flow with axial symmetry, although the analysis required to get quantitative data is, of course, much more complicated.

Opinion in Germany on the utility of the interferometer was very divided. It was applied very successfully to the study of high-speed flow through cascades of aerofoils, and was even used to find the distribution of velocity across a boundary layer. Direct comparison between the measured pressure distribution around an aerofoil, and the pressure deduced from interferometer photographs, indicated that the pressure could be obtained with an accuracy as good as 1 per cent. of $\frac{1}{2}\rho V^2$. In spite of this, many

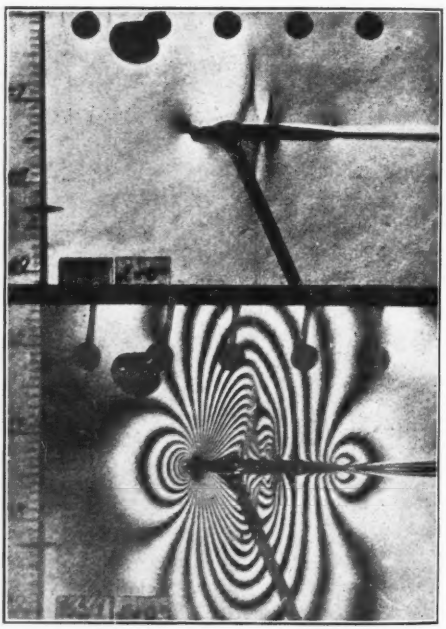


Fig. 10.
Combined Schlieren-interference picture;
Aerofoil at M 0.83.

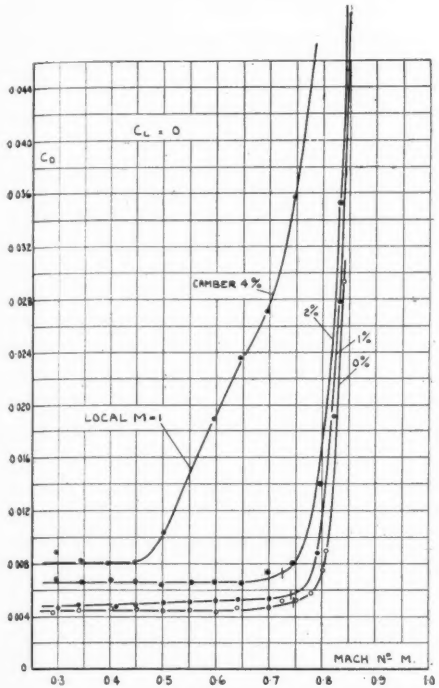


Fig. 11.
Effect of Mach No. on profile drag coefficient at $C_L=0$, for aerofoils of different camber.

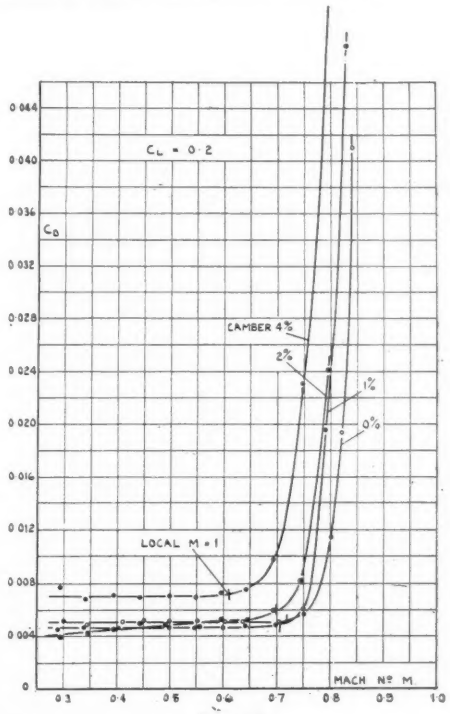


Fig. 12.
Effect of Mach No. on profile drag coefficient at $C_L=0.2$, for aerofoils of different camber.

Germans believed that the results hardly justified the excessive amount of development work which was expended on the scheme, particularly at L.F.A., Brunswick, during the war years.

4. IMPORTANT EXPERIMENTAL RESULTS—SUBSONIC SPEEDS

4.1. *Aerofoil tests at D.V.L.*

Turning now to the results which the Germans obtained from their equipment, the 9 ft. tunnel of the D.V.L. under Dr. Göthert undoubtedly contributed most to subsonic flow research. Of particular interest is the large number of systematic tests on two-dimensional aerofoils (between end-plates), measuring pressure distribution and profile drag by wake traverse over a range of incidence and Mach number. As examples, Figs. 11 to 13 show the effect on drag of cambering a 12 per cent. thick aerofoil, for a range of lift coefficient. The surprising conclusion from these curves is that the uncambered wing section is to be preferred for high-speed aircraft; even at lift coefficients as high as 0.6, the symmetrical wing section has a lower drag at the highest subsonic speeds than any cambered section. We in Britain had already begun to fit symmetrical wing sections to very high-speed aircraft before this information appeared, but with the object of reducing the changes of longitudinal trim which are a dangerous product of the shock-stall on most aircraft. The fact that the drag at high speeds is reduced with symmetrical wing sections is, of course, an added advantage confirming their superiority.

Another very important point is illustrated in Figs. 11 to 13. The Mach number at which the velocity at some point on the aero-

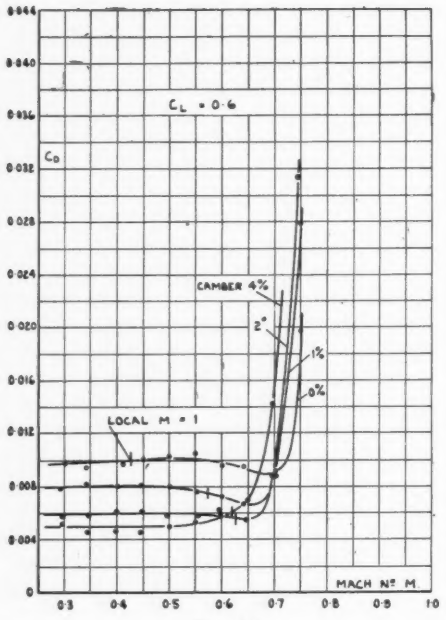


Fig. 13.
Effect of Mach No. on profile drag coefficient at C_L=0.6, for aerofoils of different camber.

foil just reaches the speed of sound locally can be computed from the measured pressure distributions, and this critical Mach number is indicated on each curve. It will be seen that this point bears no relation whatever to the Mach number at which the drag of the aerofoil begins to rise. German opinion on the significance of the critical Mach number has changed in a manner very similar to our own. In the early days of compressibility problems, the critical Mach number—usually deduced from low-speed wind tunnel pressure measurements—was regarded as the upper boundary of permissible flight speeds. A second phase, after some experiments had shown no ill-effects at Mach numbers rather above the critical, was to assume that they appeared at a Mach number above the critical value but related to it; for example, the drag coefficient might be expected to start rising at 0.05 above the critical Mach. number. The third courageous step of declaring the critical Mach number of little significance was taken only very recently. It had one important corollary; although it is possible to design wing sections with minimum excess velocities on the surface, *i.e.*, maximum critical Mach number, these will not necessarily be better than conventional wing sections. Both in England and in Germany, experiments have confirmed that there is, in fact, little to choose between the two types of wing section.

Other systematic aerofoil tests at D.V.L. included investigations of the effect of leading-edge radius (negligible) and chordwise position of maximum thickness (optimum at 0.4 chord at small incidences, farther back at higher incidences, see Fig. 14). The effect of roughness was also investigated, and is shown as a function of Mach number in Fig. 15; here 1 μ is $^1/_{25000}$ inch, and is roughly 2.9×10^{-6} of the chord. The conclusion from these results is that roughness up to about 20 μ, or 6×10^{-5} chord, has negligible effect on the drag at high Mach numbers, at the Reynolds number of the tests (about 7 millions). This condition would, however, be expected to become more severe at higher Reynolds numbers.

The D.V.L. tunnel, of course, did not confine its work to aerofoil tests; a large number of complete model tests and miscellaneous investigations were also made. The Göttingen injector tunnel assisted in many of these, and also conducted a systematic investigation into the design of nose entries for gas turbine units in high-speed flight. These will not be discussed in detail here. It is necessary to mention, however, the application of a water tank to the design of high-speed aircraft as developed by Prandtl. By running a crude model under cavitation conditions, a surface of cavitation is formed which is essentially a constant-pressure surface; thus the shape for maximum critical Mach number is immediately seen. In view of the remarks above on the significance of the critical Mach number, however, the utility of this ingenious scheme is by no means certain.

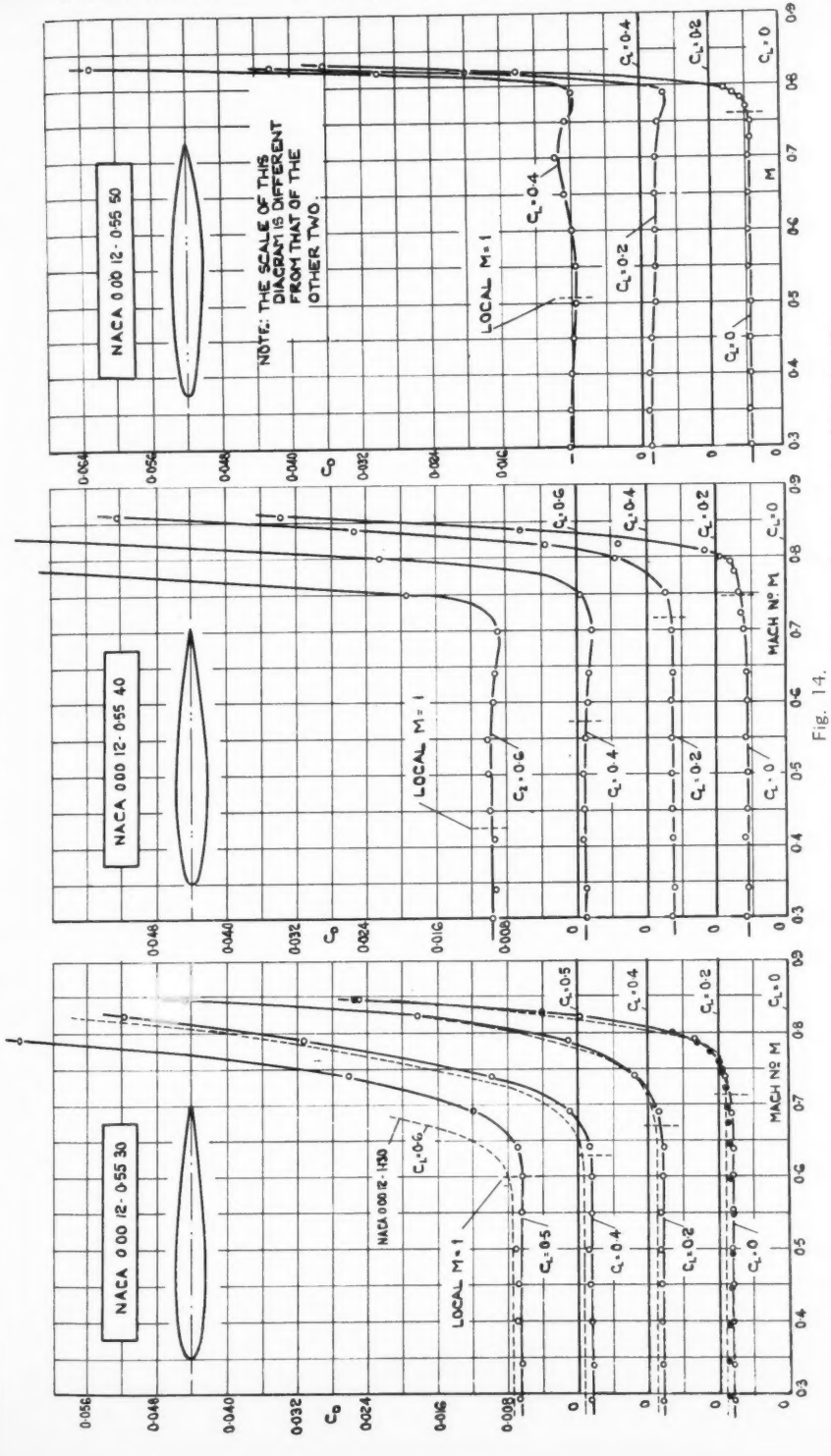


Fig. 14.
Effect of position of the maximum thickness on the profile drag of an aerofoil at high Mach Nos.
(Aerofoil chord—500 mms.)
Drag measured by wake traverse method.

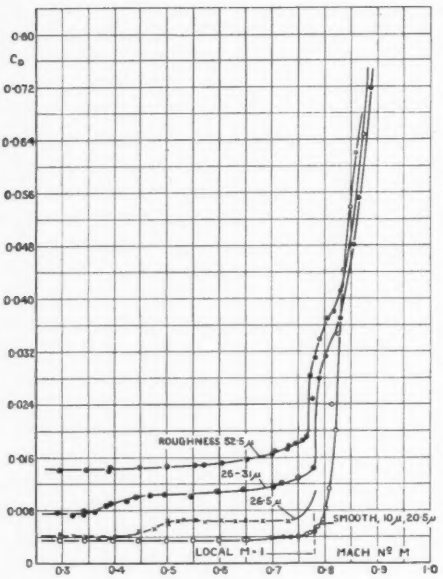


Fig. 15.

Effect of roughness on variation of profile drag with Mach No.

Aerofoil N.A.C.A. 0 00 12-0.55 50/0.5 (C=350 mm.). C_L=0.

4.2. *Sweepback*

Of far greater importance than the German work on wing sections is their recognition and development of swept-back or swept-forward wings to delay and reduce compressibility effects. The idea originated with Prof. Busemann of L.F.A., who mentioned its possible application to supersonic flight at the Volta High-Speed Congress in 1935. Apparently its application to delaying the formation of a shock-wave at subsonic speeds was put forward by Prof. Betz at Göttingen in about 1939, and since that date very many tests have demonstrated the soundness of the idea.

The principle is usually explained by considering a yawed aerofoil of constant chord and infinite span, the chord making an angle ϕ with the wind direction. Of the velocity components $V \cos \phi$ and $V \sin \phi$ along and perpendicular to the wing chord, the second, a constant velocity along the span, can have no influence on the flow and pressure distribution around the aerofoil, apart from minor effects in the boundary layer. It follows that the aerofoil behaves, from the shock-stalling point of view, as though the Mach number were not M, but $M \cos \phi$. It is easy to show that the effect of sweepback or sweepforward on lift and drag (apart from skin friction), in this idealised case, is as follows: if the unyawed wing has coefficients C_L, C_D at Mach number M, then the yawed wing will have coefficients $C_L \cos^2 \phi$, $C_D \cos^3 \phi$ at Mach number $M / \cos \phi$. Thus sweepback not only delays the Mach number at which compressibility effects appear, to a value greater in the ratio sec ϕ to 1; but it also reduces considerably the rise in drag in the shock-stalled condition.

This is an idealised condition, and in practice by sweeping back (or forward) the wings of normal aircraft it is not possible to obtain the full gain; as a general rule, the delay in Mach number before the drag rises is only some 50 per cent. of the theoretical amount. The German way of expressing this was to say that sweepback increased the Mach number at which drag rises, from M to $M \sqrt{\sec \phi}$. Even this partial gain is well worth while, however, as can be seen from Figs. 16 and 17. The first figure refers to a proposal to sweep back the wings of the jet-propelled Me.262 fighter, a modification which was in hand when the war ended. Fig. 17 shows that the fall in slope of the lift

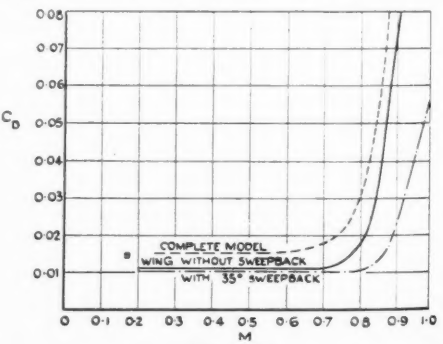


Fig. 16.

High-speed tunnel results on M.E. 262 model.

curve, characteristic of the shock-stall, is also delayed by sweepback in the same manner as the drag rise.

The reason why the gain is only partial lies in the differences between the swept-back conventional wing and the idealised infinite yawed aerofoil, *i.e.*, in the wing taper, the finite aspect ratio, and the presence of a central plane of symmetry or a fuselage. Of these, the last is apparently of most importance; clearly, the centre-section of a swept-back wing must act as an unyawed aerofoil, and will develop a shock-wave before the rest of the wing. This has been observed to happen in German wind tunnels; a short-span shock-wave appears first at the centre section, and spreads gradually spanwise as the Mach number increases. There was much talk of shaping the fuselage sides to be a streamline of the yawed aerofoil flow, but apart from some very empirical attempts at Göttingen to shape an engine nacelle for a swept-back wing, which appear fairly successful, little was done to confirm this possibility. At the end of the war, a more rational approach to the problem was made by Ludwieg at Göttingen, who calculated the critical Mach number at the centre section of a V wing of infinite span. His conclusions are reproduced in Fig. 18, which demonstrates that although the centre-section is not swept-

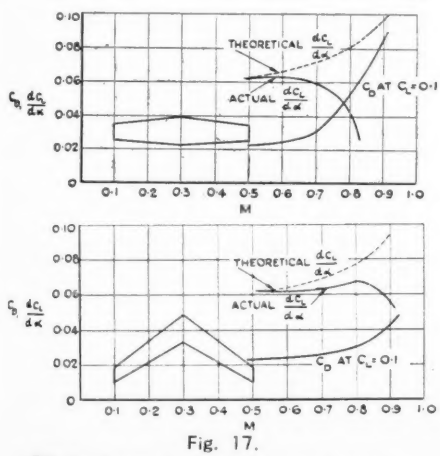


Fig. 17.
Effect of sweepback—H.S. tunnel results.

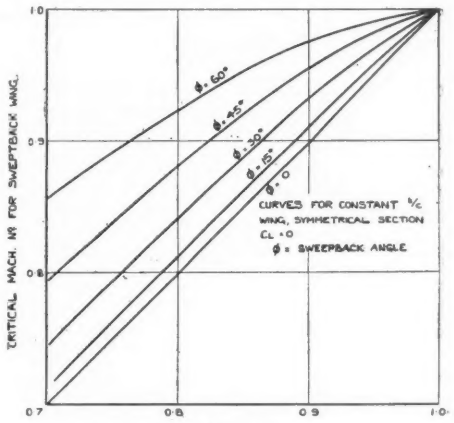


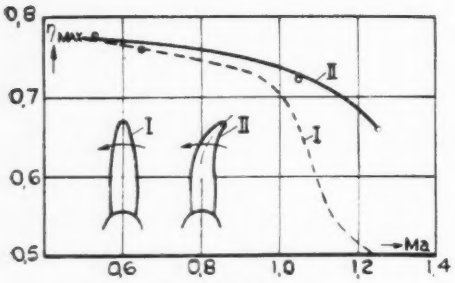
Fig. 18.
Critical Mach No. for rectangular wing.
Critical Mach No. at centre-line of V wing.

back, there is a pronounced favourable effect on its high-speed characteristics from the sweepback of the rest of the wing. It will be observed however, that although the simple theory of the infinite yawed aerofoil leads to the possibility of achieving supersonic speeds without a shock-wave, this possibility vanishes as soon as the more practical V wing is considered.

The advantages of sweepback at high speeds are accompanied by some disadvantages at low speeds and high lift coefficients. Maximum lift coefficient, without flaps, is not greatly changed by sweepback, although it occurs at a higher incidence; but flaps appear to be very much less effective on a swept-back wing. Slots are also comparatively ineffective:—

	Normal wing (Me.262)	Swept-back 35°
$C_{L\max}$ without flap, $R = 10^6$	0.9	0.9
$R = 3 \times 10^6$	1.3	1.2
$\Delta C_{L\max}$ due to 50° flap, 0.25 chord	1.3	0.45
$\Delta C_{L\max}$ due to *LE* slot, 0.15 chord	0.6	0.3

Considerable work was in progress in Germany on this aspect of the swept-back wing, and a special nose-flap, which hinged forward from the leading-edge at an angle of



Tip Mach No.

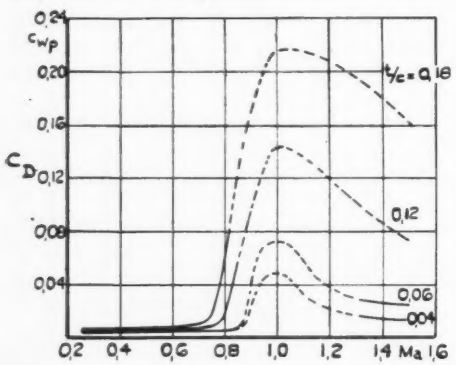
Fig. 19.

Influence of sweepback on the efficiency of an airscrew.

60° to the chord line, was developed at Göttingen to restore the maximum lift coefficient.

The danger of a wing-tip stall, and consequent wing-dropping, with swept-back wings, is, of course, well known from experience with tailless aircraft designs. To avoid it, aircraft designs with swept-forward wings are feasible; from the high speed aspect, the simple explanation above indicates that sweepforward is as good as sweepback in delaying compressibility effects. Indeed, the Germans built a bomber, the Ju.287, with swept-forward wings; it was jet-propelled and intended for very high speeds. The prototype flew satisfactorily, but was destroyed by the Allies.

It should be mentioned here that the delay of compressibility effects by sweepback is only one of two possible methods investigated in Germany. A similar delay is possible by reduction of the wing aspect ratio to very small values. As this idea is more appropriate to flight at supersonic speeds, however, it will be discussed in detail in a subsequent paragraph.



Mach No.

Fig. 20.

Drag coefficients of profiles.

4.3. *Propeller research*

Although the turbo-jet unit was definitely taking the place of the airscrew for high-speed propulsion in Germany as in England, some work was done on airscrews for very high speeds. Two aspects of this work are of considerable interest. First, the application of the sweepback principle to the tips of an airscrew permits the efficiency to be maintained above 70 per cent. for tip Mach numbers up to nearly 1.2. This is shown in Fig. 19, which gives experimental results from Göttingen on the efficiency of a model airscrew with tips swept-back through 45°. Calculations showed that a similar full-scale airscrew could be made structurally quite sound.

The second suggestion was for an airscrew with sections operating at supersonic speeds throughout. Fig. 20 shows the measured drag coefficients of aerofoil sections at sub and supersonic speeds (the portion between 0.85 and 1.25 is estimated), and illustrates the rapid fall in coefficient above the speed of sound. Dr. Quick at D.V.L. designed an airscrew with all sections operating at a Mach number above 1.3, and showed by calculation that efficiencies of the order of 70 per cent. were quite feasible. A very large hub diameter and very high rotational speeds are necessary; such propellers may thus prove very useful for direct drive by turbine power plants.

4.4. *Application of wing suction at high Mach numbers*

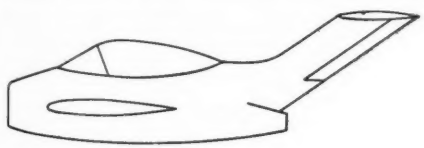
Work was done both at L.F.A. and at Göttingen on the effects of suction applied on an aerofoil at high speeds, through a slot behind the shock-wave at about 0.7 C. With the best slot position a maximum delay in the drag rise of about 0.1 in Mach number could

be obtained; the flow required was given roughly by $C_Q = \text{flow}/V \times \text{wing area} = 0.004$. This means a flow of 600-800 cu.ft./sec. for a typical small fighter, which is quite a large amount, of the same magnitude as the flow demanded by typical jet propulsion units.

Although it is a difficult practical proposition to apply suction in this manner along the whole span of an aircraft, the results may have considerable utility in the delay of local compressibility effects at points such as wing-body or wing-nacelle junctions; particularly if the wing sweepback promotes early shock-stalling here as explained in para. 4.2.

4.5. *Influence on high-speed aircraft design*

It is surprising that very little of the experimental work described above had any great influence on aircraft in operational use at the end of the war. The later jet-propelled fighters had symmetrical thin aerofoil sections, adopting the results of the aerofoil work described in para. 4.1; but large angles of sweepback had not appeared on any operational aircraft when the war ended. There was ample evidence of its universal adoption in high-speed aircraft designs at the prototype or project stage, however. Apart from the Junkers 287 swept-forward bomber, which has already been mentioned, there were a whole series of fighter aircraft projects with swept-back wings, some of which were almost built in prototype form. Figs. 21 and 22 show Focke-Wulf and Messerschmitt designs which illustrate the general trend. It will be observed that the Messerschmitt design has no tail; there was clearly some doubt in the German designer's mind as to the necessity for a tail with high sweepback



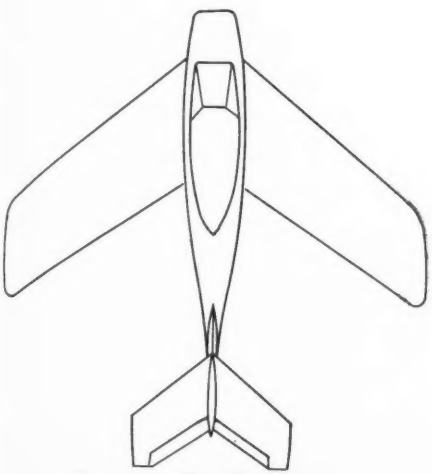
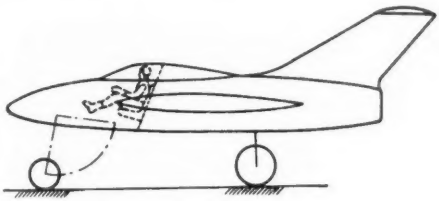


Fig. 21.
Focke-Wulf T.A. 183 fighter.
(Not to scale).



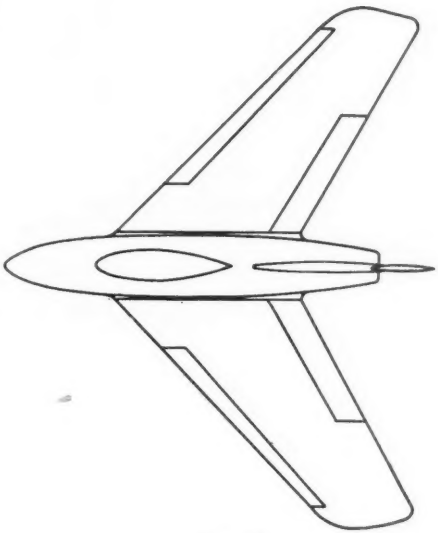


Fig. 22.
Messerschmitt P.1111 fighter.

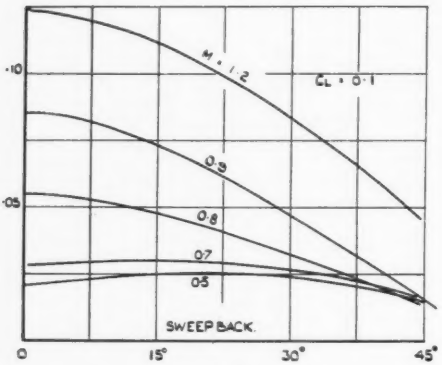


Fig. 23.
(b) Effect of sweepback on drag at high Mach No. (Ref. 13).

angles, and Messerschmitt, for example, went so far as to provide alternative versions with and without tailplane. This doubt has not yet been resolved in England.

5. SUPERSONIC RESEARCH

5.1. *Sweepback and low aspect ratio*

In the back of every German research worker's mind there seemed to be the idea that supersonic flight was just around the corner; an idea justified by the promise of sweepback and the introduction of jet propulsion. The benefits of sweepback hold in the near supersonic range (up to about $M = 1.5$ with reasonable sweep-back angles), as can be seen from the wind tunnel results at $M = 1.2$ reproduced in Fig. 23. It is probable, however, that for supersonic speeds the use of low aspect ratio wings with leading-edge sweepback will replace the more normal swept-back wing. The Germans found low aspect ratio to have much the same effect as sweepback in delaying compressibility effects, as can be seen by comparing Fig. 24 with the corresponding figure, Fig. 18, for the effect of sweepback. The low aspect ratio wing has the obvious advantage that it eases the difficult structural problems of supersonic flight, whereas the swept-back wing of normal aspect ratio increases the difficulties.

While the low aspect ratio wing is not feasible for subsonic flight application, because of the high induced drag, induced effects are in general negligible at supersonic speeds and the low aspect ratio is permissible. The aircraft will have to land (it might take off vertically), and the very high landing incidences for reasonable lift at low aspect ratio constitute a real practical problem.

Considerations of this sort prompted Lippisch and others in Germany to concentrate on aircraft of the type shown in Figs. 25 and 26. The construction of an aircraft as in Fig. 25 was begun in June, 1944; that of Fig. 26 was a later project. Lippisch claimed that the low-speed control problems of such aircraft were in fact, much simpler than those of tailless aircraft of more normal aspect ratio; the tip-stalling difficulty disappears when the aspect ratio is reduced below about $2\frac{1}{2}$.

The aircraft of Fig. 26 is clearly to be regarded, for the present at least, as the extreme of development in the direction of reduced aspect ratio. Its drag as a function of Mach number, measured on a model at Göttingen, is shown in Fig. 27. The results justify consideration of so unconventional a plan-form; it will be observed from Fig. 27

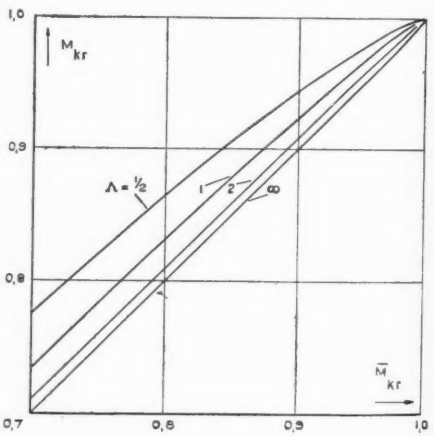


Fig. 24.
Critical Mach No. M_{kr} of a rectangular wing of the aspect ratio Λ plotted against the critical Mach No. M_{kr} of a wing of infinite aspect ratio and the same profile.

that the maximum drag coefficient in the transonic regime is 0.04, which is not greatly in excess of that of many aircraft now flying at low Mach number.

Consideration of the longitudinal stability of supersonic aircraft, and of the changes which occur in accelerating through the transonic speed range, shows that from the point of view of achieving minimum change, the adoption of such unconventional wing planforms is desirable. We in Britain seem to have had a much clearer appreciation of this problem and its possible solutions than the German workers. As early as 1944 we realised that aircraft of conventional design would all suffer a very pronounced increase in longitudinal stability in the transonic speed range; an increase equivalent to 0.5 chord (or more) forward movement of the C.G. of the aircraft. Several methods of overcoming this, involving the use of tailless or tail-first layouts and triangular wings or wings of low aspect ratio, were suggested at that time.

The German scientists were aware of the increase in longitudinal stability, but their attempts to minimise it were very empirical in character—a most unusual event in German aeronautical research, probably a consequence of the urgency with which the solution was wanted for guided missile application. Thus at Kochel, the major problem in the development of the supersonic guided missile "Wasserfall" was to achieve a roughly constant "neutral point" at subsonic and supersonic speeds; and this was done by testing a whole series of wings and tailplanes, some of which are shown in Fig. 28. The final version, third from the left in Fig. 28, had a neutral point movement of less than 0.03 chord over the whole range of Mach number from 0 to 2.5. The change in wing plan-form from the original version at the right-hand side is noteworthy.

A similar series of experiments on the rocket A.9, which was a winged version of the V.2 rocket designed for much greater range, showed the same difficulty in obtaining satisfactory longitudinal stability above and below the speed of sound, and in this

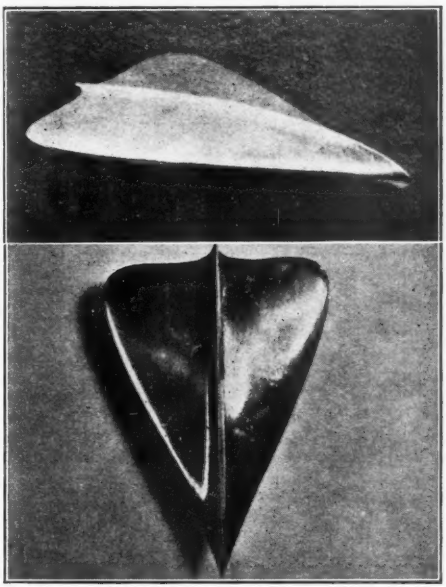


Fig. 26.
Lippisch P.13 model.

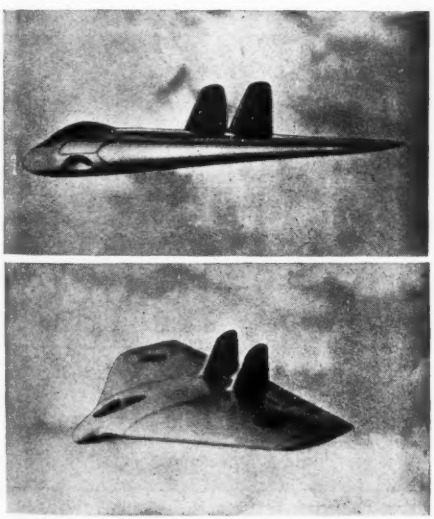


Fig. 25.
Lippisch P.11.

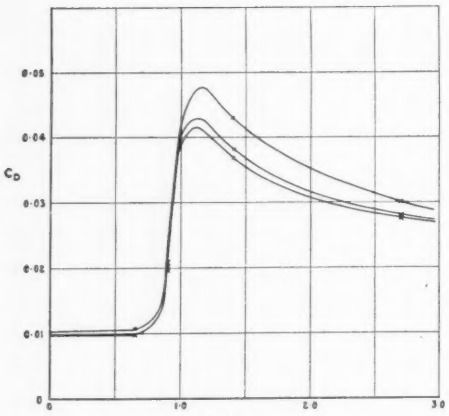


Fig. 27.
Drag of Lippisch P.13 aerofoil at high speed.

case no really satisfactory solution was obtained.

Before leaving the subject of wings of small aspect ratio, the large amount of work on their low-speed characteristics should be noted. The series shown in Fig. 29 was tested at the D.V.L., and slope of the lift curve $\frac{\partial C_L}{\partial \alpha}$ and aerodynamic centre distance h behind the mean quarter-chord point were measured. A few results on triangular wings are given in Table II. It is of interest to note that results confirmed Lippisch's statement that no wing-dropping tendencies appeared at aspect ratios below about $2\frac{1}{2}$; and that maximum lift coefficients of about 1.0 were obtained with aspect ratios of 1 to 2, but at incidences of nearly 40°. The superiority of low aspect ratio triangular wings in reducing the stability change at transonic speeds is apparent from the last two lines of Table II.

5.2. *Supersonic aircraft*

Much of the supersonic work in Germany during the war was of course aimed at developing projectiles and guided missiles, although in many instances the results point the way to future supersonic aircraft, as indicated in the paragraphs above. An Institute in Vienna under Dr. Lippisch was studying the supersonic aircraft, however, and the proposals shown in Figs. 25 and 26 were originated there. In addition, the D.F.S. (Deutsch Institut für Segelflug) at Ainring was constructing an experimental aircraft powered by two bi-fuel rocket units, intended primarily for aerodynamic work at Mach numbers up to 1.4 (although estimates of its performance indicated a maximum Mach number of 2.7). A wing of 35° sweepback and normal aspect ratio was proposed, with a tail of conventional type; apparently the intention was merely to accept the longitudinal stability increase. In fact, it appeared that much more ingenuity had been expended on problems of pilot's escape than on aerodynamics; possibly a wise step!

5.3. *Supersonic diffusers*

The problem of efficient conversion of kinetic energy to pressure at supersonic speeds is, of course, of major importance to turbo-jet or ram-jet power plants for supersonic speeds, when the pressure ratio obtainable by slowing the stream is sufficient to

TABLE II
TRIANGULAR AEROFOIL CHARACTERISTICS AT LOW MACH NUMBER

Aspect ratio	3	2	4/3	1
Apex angle (degrees)	73.8	53.2	36.8	28
$\partial C_L/\partial \alpha$	2.7	2.1	1.6	1.23
Aerodynamic centre h	0.125	0.165	0.19	0.215
A.C. at supersonic speed*	0.33	0.33	0.33	0.33

* Roughly at supersonic speed the aerodynamic centre is at the centre of area; this, compared with the value of h at subsonic speeds, indicates the longitudinal stability change.

give quite an efficient thermodynamic cycle. The problem also has an important side-line in the design of supersonic wind tunnels.

A major contribution in this field was made by Oswatitsch of Göttingen. He suggested that the normal shock which appears in the entry of a duct at supersonic speeds could be replaced by several oblique shocks, across which the compression of the air would occur much more efficiently. The practical method of achieving this, by means of a central core in the entry, is shown in Fig. 30. The position of the outer lip relative to the nose is chosen so that the nose wave impinges on it, and further oblique shock-waves are located by corners in the profile of the central core. Several oblique shock-waves in series along the entry duct, ending with a final normal shock of small strength, are indicated in Fig. 30; the greater the number of oblique shocks, the better is the pressure recovery in the diffuser. This is demonstrated in Fig. 31, which is extracted from recent British work, and compares the pressure recovery $p\delta$ ($p\delta$ is the ratio of the actual pressure increase in the diffuser to that which would be obtained in isentropic flow, *i.e.*, without shocks) for the Oswatitsch type of diffuser and the usual type of pitot entry with normal shock-wave. It will be seen that the gain in pressure, at Mach numbers above 2, is very large with two or three oblique shocks; above this number the further gains are not great.

These theoretical expectations were confirmed in Germany by supersonic tunnel tests at L.F.A. and A.V.A. Fig. 32 shows the results of A.V.A. tests at $M=2.9$. The maximum pressure obtained was just over

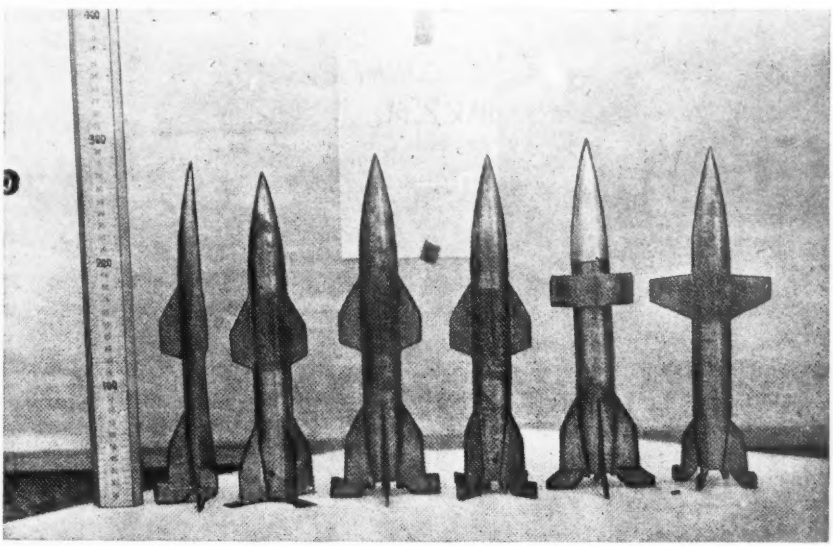


Fig. 28.

(*Left to right*) Wasserfall development.

(i) Half model of final version for pressure plotting experiments.
(ii) Final version—standard model for 3-component balance measurements.
(iii) Final version—model for dynamic stability measurements with jet flow (the entry for the compressed air supply can be seen in the junction of two of the wings).
(iv) Composite model for varying wing position and orientation relative to fins.
(v) Shroud wing version—drag prohibitive at high subsonic speeds.
(vi) Original contractor's design—unstable and unacceptably large centre of pressure travel through the speed of sound.

0.7 of the isentropic ideal, whereas at this Mach number a pitot tube records a stagnation pressure of only 0.35 of the isentropic value. The significance of this change will be appreciated when it is realised that a power unit working in the duct would be accepting air at 20 atmospheres pressure in the first case, and only 10 atmospheres in the second.

The only practical difficulty with diffusers of this type is to design them satisfactorily for a wide range of Mach number. The angle of the shock-waves, of course, changes with Mach number, and at Mach numbers well away from the design value the shock-waves from the corner no longer meet the outer lip. There is then a loss of compression efficiency. The obvious remedy of altering the diffuser shape with the Mach number presents quite a complicated mechanical problem.

6. RESEARCH AT TRANSONIC SPEEDS

6.1. *The general problem*

Every worker in the high speed field very soon comes up against the major problem of theoretical or experimental work in the immediate vicinity of the speed of sound. Well before the speed of sound is attained in subsonic wind tunnels, the flow ceases to represent that of the model in free air and the whole tunnel becomes in effect a convergent-divergent nozzle. This limits the useful Mach number to a maximum of 0.85 to 0.9. Approaching from the supersonic side, a parallel difficulty appears; the reflection of the nose-wave of the model from the tunnel wall, which at high supersonic speeds passes aft of the tail of the model, moves forward until it meets the model itself. In practice, this limits the application of such tunnels to Mach numbers above about 1.2 to 1.3.

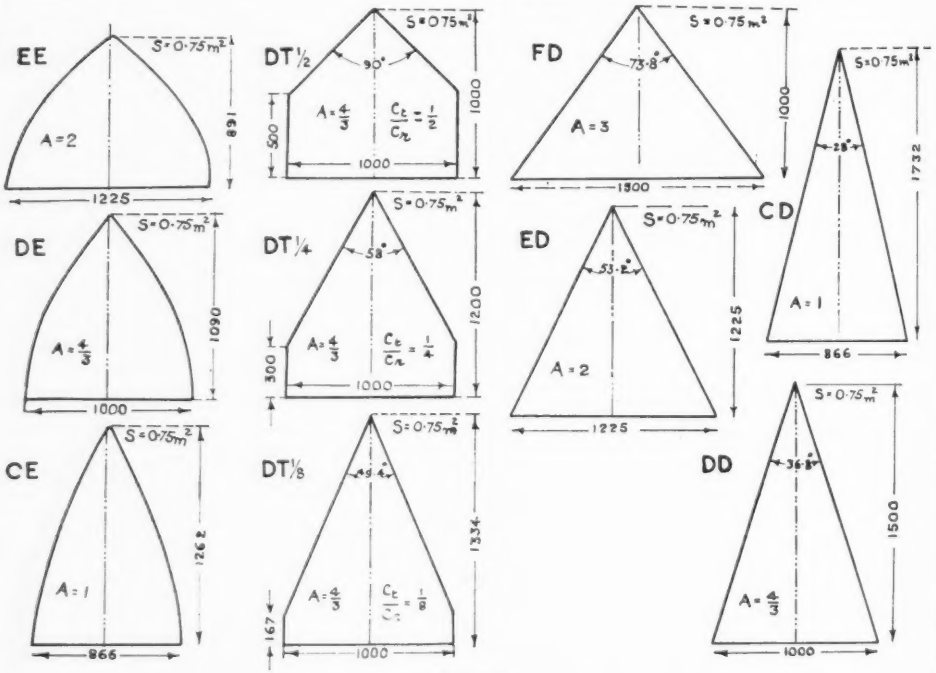


Fig. 29.
Scale 1/20.
Profile N.A.C.A. 0012.
18607 S.

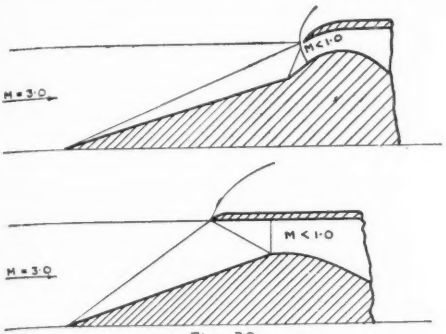


Fig. 30.
Multi-shock diffusers.

The experimental difficulty is accompanied by extreme difficulty in the theoretical analysis of mixed supersonic and subsonic flow, such as occur around the aircraft in this transonic region. The problem has, in fact, proved so intractable that no adequate theoretical approach has yet been devised.

Unfortunately, it is in this difficult region between Mach numbers of 0.8 and 1.3 that many of the most important changes in aerodynamic characteristics occur. Accordingly, many workers in several countries have attempted to solve the problem of suitable experimental techniques; and the German proposals for this purpose are thus of considerable interest.

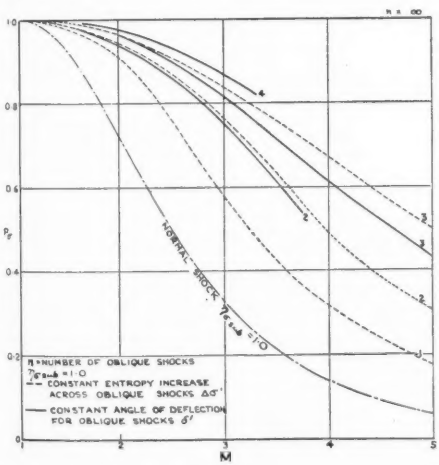


Fig. 31.
Maximum pressure recovery of multi-shock two-dimensional supersonic diffusers ($\gamma=1.4$).

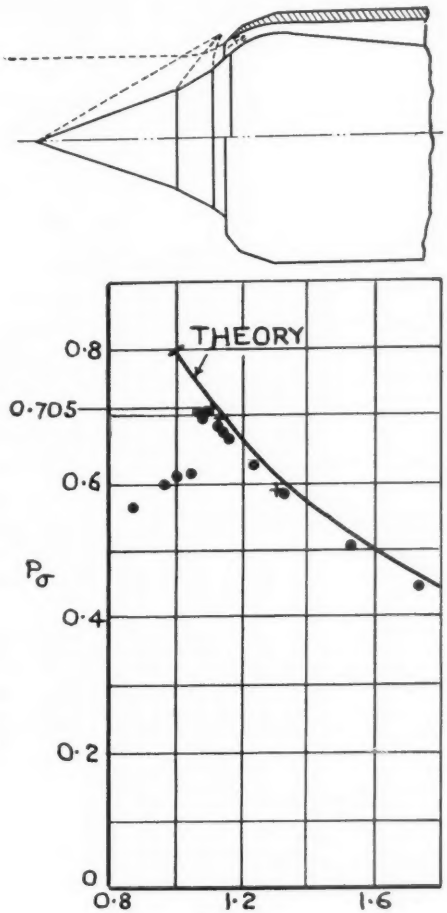


Fig. 32.
F_D/F_e
•= Incidence $\alpha=0°$ } M=2.9
+= Incidence $\alpha=5°$ }
F_D = Adjustable diffuser exit area.
F_e = Diffuser entry area.
Oswatitsch's multi-shock diffuser No. 111. (Ref. 10).
Design Mach No.=2.9.

6.2. *Wind tunnel improvement*

Two possible methods of extending the application of wind tunnels farther into the transonic range were suggested at A.V.A. Both relied on the fact that the wind tunnel corrections at subsonic speed, and the strengths of the reflected shocks at super-

sonic speeds, are of opposite sign for open-jet and closed-wall wind tunnels. Thus if a part-open, part-closed tunnel of suitable design could be evolved, it might be possible to have negligible corrections in the transonic range.

One suggestion was to choose a point on the axis of an open-jet tunnel very near the tunnel nozzle, where the closed wall of the nozzle would apply an opposite constraint to that of the jet. This clearly is of no value at supersonic speed, but would possibly permit testing at higher subsonic speeds. A very complicated mathematical analysis indicated the appropriate point at low Mach numbers, but the problem with compressible flow was not solved, and no experimental work was done.

A suggestion of more potential value was to have an open-jet tunnel surrounded by an annular second jet of different velocity with a closed outer wall. The difficult calculation of appropriate dimensions and velocities was undertaken at Göttingen, but was not completed; and again no experimental work was done.

6.3. *Moving models in free air*

A proposal to experiment on a model mounted on a carriage, travelling along rails at speeds near the speed of sound, was investigated in some detail at A.V.A. The carriage was to be accelerated by a bi-fuel rocket, and the problem of rail friction was to be overcome by electro-magnetic suspension without actual contact between carriage and rail. Nothing was made, however. In fact, only two proposals for transonic experiments reached the experimental stage; both involved the use of models in free flight.

The first of these was a series of bomb-dropping experiments made in the south of

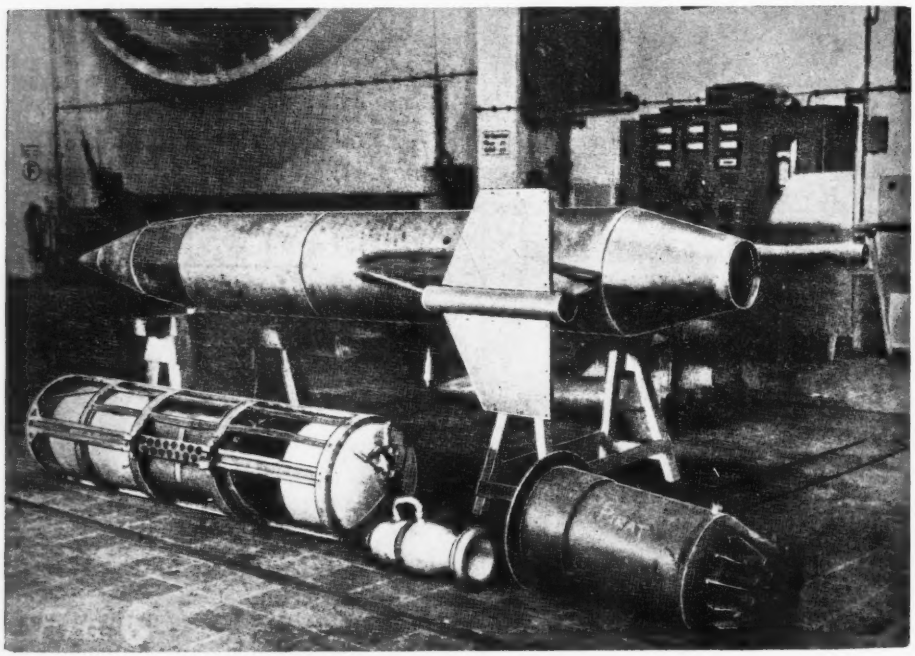


Fig. 33.
Transonic model "Feuerlillie."

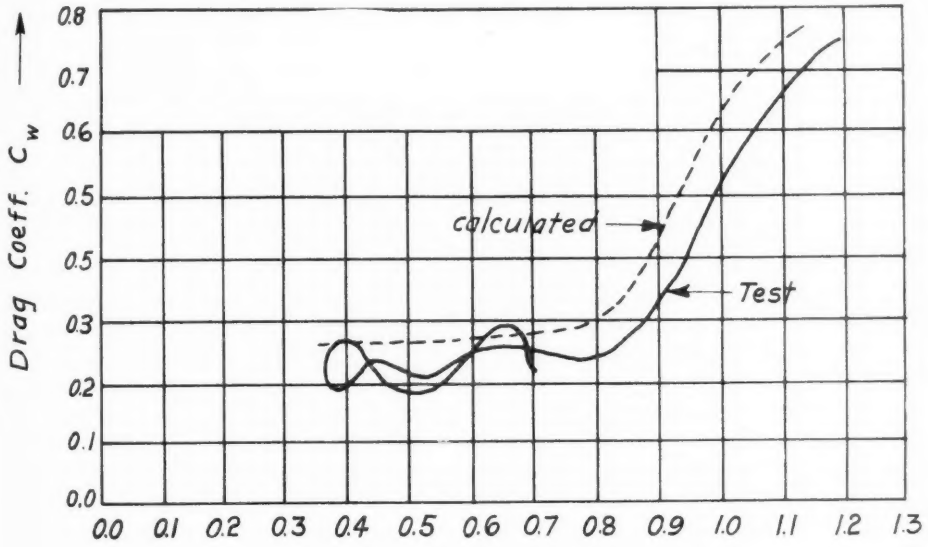


Fig. 34.
Drag coefficients for "Feuerlillie" F. 55 rocket.

France under the direction of Dr. Göthert of the D.V.L. The main object of these tests was to check the correctness of the corrections being applied to results in the D.V.L. 9 ft. high-speed tunnel; they were, therefore, arranged to explore only the lower part of the transonic speed range, up to $M=1.0$. Bombs of differing weights were dropped from a height of roughly 35,000 ft., some fitted with aerofoils. They were followed visually by kine-theodolites, which gave the flight path; differentiation of the path with respect to time gave velocity and hence Mach number, and double differentiation gave acceleration and hence drag. Good confirmation of the wind tunnel results was obtained, within the accuracy of the experiment—which was not very great.

A rather more complicated series of experiments, reaching higher Mach numbers, was started by Dr. Braun at L.F.A. These employed rocket-propelled models with combined lifting and control surfaces; they were launched from the ground at an angle of 70° to the horizontal. It would have been preferable to launch the model from an aircraft and to accelerate in level flight, so as to attain a higher Mach number in steadier conditions; but the programme was laid down with the idea of using such a vehicle as a guided anti-aircraft rocket. This had considerable influence on the shape as well as on the launching technique. Fig. 33 shows one of the later versions; it is tailless, with swept-back low aspect ratio wings set well back on the body. It was given a name "Feuerlillie," by the Germans.

Some 20 models of an initial small design were launched, many successfully; but as they did not exceed a Mach number of 0.7, they are not of much aerodynamic interest. Work had only just started on the larger model of Fig. 33 at the end of the war; one, weighing 1,000 lb. and driven by a solid-fuel rocket of 13,000 lb. thrust, had been launched successfully and followed by kine-theodolite. The results, in the form of a curve of drag coefficient against Mach number, are shown in Fig. 34; they are compared with a calculated curve based on

wind tunnel tests at low Mach numbers and on ballistic data at higher speeds. Possibly more interesting than the drag data is the fact that the model remained under control by its automatic pilot up to its maximum Mach number of 1.25, although it had a conventional wing section (N.A.C.A. 0009) and ailerons of normal type.

The value of these free-model tests, both bomb-dropping and "Feuerlillie," would have been greatly increased if more accurate methods of obtaining trajectory data had been employed. The double differentiation involved in the derivation of results from kine-theodolite readings is a very inaccurate process, even if carried out with extreme care; the Germans were well aware of this, and attempted to improve it by dubious processes involving the fitting of high-degree polynomials to the trajectory curve, and analytic differentiation. A better method is to measure the acceleration directly, by transmitting from the model readings of an accelerometer; at the end of the war, work on a radio transmitter for this purpose was begun at D.V.L., but it did not reach the stage of application to the model.

7. CONCLUSIONS

This short extract of some of the major points of the German high-speed work shows, it is hoped, the immense scale of effort in this particular branch of aerodynamic research. The major interest of practically every first-class aerodynamicist in Germany, all full of enthusiasm for the subject, backed officially, and helped by superlative equipment, it is not surprising that advances of major importance were made. Ideas were there in plenty; some of them, such as the application of sweepback and low aspect ratio, show promise of marking a new era in aeronautical design.

Yet, from the German point of view, almost the whole of this effort was wasted. The new conceptions summarised above, combined with their developments in jet propulsion—it should be remembered that their first jet-propelled aircraft flew at the end of 1938, over two years before ours—these, together, should have given them a healthy lead in fighter speed over any other country. That this advantage, fortunately, did not materialise can be put down to two causes; the extraordinary inertia of German aircraft firms, and the comparative isolation of the research workers from the industry.

With the former we are not concerned, except to point out that the development of jet propulsion in Germany is probably the worst example. The gap between the research worker and the aircraft industry did not appear on the surface; there were occasional joint discussions on important subjects. But it was soon apparent when conditions were examined in more detail. Thus, for example, high-speed wind tunnel tests were made at D.V.L., A.V.A., or L.F.A. on practically every fighter and some high-speed bombers, but the research workers there knew very little of the results; the firm sent its own operators to make the tests, and took away the results for analysis in its own design office. One result of this was that each firm was compelled to maintain a very large staff of technical men, particularly aerodynamic specialists. As an example, the design office of Focke-Wulf consisted of 350 first-class technical men and 250 designers; a most unusual combination compared with British practice.

When the fact is borne in mind that flight research was on a negligible scale, it becomes clear that the average research worker — apart from a few at the D.V.L. — had virtually no contact with the final object of his research, the aircraft itself. In consequence much of his effort was expended in research of a general or fundamental nature; usally he did not know, and did not seem to care, whether any use was being made of his work. For some purposes such an outlook is invaluable, and it may have contributed to the German advances in high-speed flow;

but the overall improvement to German aircraft would have been much greater if co-operation between industry and research had been as close as in Britain.

Because of this gap in their research organisation, the Germans have given us a whole series of suggestions for high-speed aircraft, almost entirely untried or inadequately tried in flight. British research workers, and, more important, the aircraft industry, are absorbing and developing these ideas, and are showing signs of making more use of them than the Germans themselves were able to do.

ACKNOWLEDGMENT

The collection of the data presented here from its German sources was the joint work of many British aerodynamicists, from the aircraft industry as well as the research stations. The author has drawn freely from their work in producing this summary; and he wishes to thank all those, too numerous to mention individually, who have contributed in this manner.

DISCUSSION

Professor von Karman (Californian Institute of Technology): When the paper was published as a report it would be appreciated on both sides of the Atlantic that Mr. Smelt had not merely reproduced the information he had obtained in Germany, but had presented it ably, systematically and in an original manner.

At the 1935 conference there were many people who were interested in high-speed flight and in the Continental work in that field. For instance, there were Mr. Jacobs and himself from the United States, G. I. Taylor and other researchers from this country. There was a sketch by Crocco on the programme of the conference, showing Busemann's suggestion of swept-back or swept-forward wings to delay and reduce compressibility effects. Both Jacobs and himself had thought it was not complete, but neither of them could be sure. It was interesting to note how such things could be forgotten for a number of years.

Mr. Smelt had mentioned that there was no correlation between the critical Mach number and the Mach number where the velocity of sound was reached. There was not yet a complete explanation, but an upper limit was given by the limiting line, which he believed was discovered by Tollmien. There was a certain Mach number for every form, beyond which no solution could be given by theoretical means; it was an upper limit in the sense that beyond it the drag would certainly increase. But the curious fact was that, although the Germans had discovered it before the war, and it was first explained in the United States in his own paper in 1939, there was no application of it throughout the war.

The Lodograph theory of compressible flow which was started by Chaplygin was employed in this country, in America and in France, but little progress had been made with it by the Germans. The same applied to the linear compressible flow theory.

During his visit to Germany he had gained the impression that the association between the mathematicians and the experimentalists was not very close; the mathematics were so complicated that the practical men did not understand them. He hoped they would not make the same mistake in this country.

An exception, where theoretical investigation was in close agreement with practical experiment, was the work of Oswatitsch on shock and diffusion. That was really a case of combined mathematical and experimental research.

Dr. G. P. Douglas (Royal Aircraft Establishment, Fellow): He had also been privileged to see some of the research equipment and to inspect the research work in Germany. The terrific effort which the Germans had put into that work and their tremendous technical achievement was impressive. They should

consider what could be learned from it all. He was impressed by the comfortable conditions in which the research staff there had worked. They had very comfortable, roomy offices, they had good assistance in the way of mechanical computing aids, and so on. He was amazed even by the special graph papers provided at their research stations; it was a revelation to English workers, who were accustomed to ordinary squared paper, and nothing else. That was something they could learn from the Germans.

In contrast to the very able work that was done on the technical side, he was impressed by the lack of higher direction. For instance, Mr. Smelt had drawn attention to the 100,000 h.p. wind tunnel at Otztal, in Austria. They had been working on the construction of that tunnel at full strength right up to the time of the armistice. It could not possibly have come into use for a couple of years, and yet it had not occurred to anyone to divert the men to more useful war work.

Again, in respect of the tunnels which were constructed during the war there was surprising lack of co-operation between the scientists and the people responsible for the erection. There were marvellous mechanical schemes for varying the test sections which were so badly made that they could not work. The impression was that the scientists had told the structure men what they wanted, and had then been told to keep away until the job was finished. The results were not satisfactory.

Mr. Smelt had rather emphasised that Göthert's tests had shown that a minimum Reynolds number of about five millions would be satisfactory for subsonic investigations. That was an inspired guess by Göthert, partly because it was forced on him to justify the equipment he was using. He did not think the experimental work was quite so systematic and conclusive as might be gathered from Mr. Smelt's remarks.

While British scientists were studying German research in great detail and were giving a lot of publicity to it, quite justifiably, he hoped they were not forgetting their own recent achievements and were ensuring that those achievements were not lost sight of as the result of enthusiasm for inspecting the German work. For instance, the problem of delaying compressibility rise by suction, which Mr. Smelt had mentioned as having been tried in Germany, had also been tried in this country. He believed that it was carried to about the same stage in both cases, although it was not applied.

Finally, it was very valuable indeed to have, from a scientist of Mr. Smelt's ability, a bird's-eye view of the tremendous mass of information on the subject of the lecture available from German sources. Mr. Smelt had done the job excellently.

Mr. W. A. Mair (Manchester University, Associate Fellow): The author had rightly emphasised the rather surprising lack of balance between German wind tunnel and flight research on high-speed problems. This might lead many people to wonder whether the results of these high-speed wind tunnel tests could be applied with any confidence to flight conditions. All that could be said was that the work of Göthert in the D.V.L. tunnel was, as far as could be seen, very reliable: as reliable as any wind tunnel tests could be at present. The conditions were carefully controlled, the humidity was rightly limited to a sufficiently low value, and the Reynolds number was fairly high, although as Dr. Douglas had suggested, it might not have been high enough. On the whole, so far as they knew, the experimental technique was good, and they should be able to apply the results with some confidence. The conditions in some other experimental establishments were not quite so good; but Mr. Smelt had been careful only to quote the results which could be considered reliable.

With reference to the results which Mr. Smelt had shown, of tests indicating the superiority of a symmetrical aerofoil over a

cambered one as regards drag, of course, the lower drag was only one of the many advantages of a symmetrical aerofoil for use at high speeds; that had been realised in this country, and he believed Mr. Smelt was the first to point out here the advantage to be gained in high-speed flight, by using a symmetrical aerofoil to reduce the trim change at high Mach numbers.

One more important variable in aerofoil shape, which the Germans began to consider and which probably ought to have been considered as fully as the others, was the shape of the rear part of the aerofoil.

At the D.V.L. they had made tests to show that, by reducing the trailing edge angle and thinning the rear part of the aerofoil, they could effect a very great difference in the behaviour and position of the shock waves on the aerofoil, and in the changes of shock-wave position with incidence. These effects ought to be investigated further in much greater detail.

Mr. A. Robinson (College of Aeronautics, Associate Fellow): Mr. Smelt had referred to Professor Sauer's book, which contained an excellent summary of the present position with regard to the theory of compressible flow, and although he agreed that there was not sufficient time for Mr. Smelt to go into the theoretical part of his subject in detail and, therefore, such a reference was very convenient, it should be pointed out that Sauer's book was far from complete. It made only a passing reference to Schlichting's paper on the supersonic theory of aerofoils of finite span, and it did not refer to Busmann's work, perhaps for reasons of security.

With regard to critical Mach number, after listening to Mr. Smelt he had the impression that, after a good deal of effort over quite a few years, both the Germans and British had arrived at exactly the point at which they had started. In actual fact, the position was not quite as bad as that. He would have thought that the critical Mach number was at least the lower limit of the Mach numbers, where the drag actually began to rise. He had noted that that contention was not borne out on one of the aerofoils which Mr. Smelt had illustrated, but he would be inclined to suggest that in that case the critical Mach numbers might not have been calculated correctly, or alternatively that the early rise in drag in that case was not due to compressibility.

Had Mr. Smelt any information about other efforts to find something to replace the critical Mach number? One method, which had been considered in the United States as well as in this country, was to take, not the total velocity, but the component velocity, in a certain direction. Another, which he believed had originated in Germany, depended on whether any shock-wave which originated on the aerofoil surface finally diverged away from the aerofoil surface or converged back to it.

With regard to sweepback, had the Germans tried to justify their $M\sqrt{\sec\phi}$ rule? Further, in addition to trying to shape the fuselage, so as to obtain quasi-two-dimensional flow, had Mr. Smelt obtained news of any similar effort with regard to the wing tips?

Concerning the relative importance of the beneficial effects of sweepback and of low aspect ratio, his impression was that, at least at supersonic velocities, the main consideration was the sweepback of the leading edge, and that the shape of the trailing edge (in planform) was comparatively unimportant. That was why Lippisch's model showed so low a drag.

The Germans could not possibly have turned out something like the Me.1111 before 1945, and but for their defeat they would have turned it out towards the end of 1945. But he believed that one of the reasons why they had been unable to save this small but critical margin of time was that there was not available, as there was in this country,

a body of people who were prepared at the very earliest moment to interpret scientific results in terms of their practical importance. Mr. Smelt was one of those people in this country.

Mr. R. Kronfeld (Associate Fellow): He spoke from the point of view of an independent consultant and test pilot, and had flown six different types of tailless aircraft with swept-back wings of various forms. From the practical side the position with regard to wing-tip stall did not appear to be half as bad as was expected. Judging from the information published about the de Havilland 108, their experience seemed to have been the same.

He was impressed by Mr. Smelt's remark concerning the work the Germans had done by way of ensuring that the pilot would get out if trouble occurred with his machine. In the development of any practical aircraft of that sort it was important to study that problem. His was perhaps a selfish interest, but it would be interesting to know more about the German work in that direction.

He agreed with other speakers that they must be careful not to over-estimate the German effort. As one of the fortunate few who had been able to visit Volkenrode and to see the facilities there, he agreed that the facilities provided for research were very good.

Mr. A. R. Weyl (Associate Fellow): To complete the picture presented by Mr. Smelt's paper, he would like to draw attention to the work of Professor J. Ackeret in Switzerland. Ackeret had been a pupil and collaborator of Professor Prandtl at Göttingen and had helped to lay the foundations for the German research work on gas dynamics. Ackeret had published quite recently an important experimental investigation on the inter-relation between the boundary layer and the shock-stall, with special reference to a form of the shock-wave which was also evident in the Schlieren photographs presented by the lecturer. This shape of the compressibility shock had been termed by Ackeret, the λ-stall.

As known, the shock-wave did not originate at the surface of the aerofoil, but within the boundary layer. Previously, it had been presumed that the state of flow within the boundary layer had influence upon the form or the occurrence of the shock-stall. Professor Ackeret had now established in the Zurich supersonic wind tunnel, that when the boundary layer was laminar, the shock-wave formed was *oblique*. Now an oblique shock-front only affected the component of the flow-velocity which was normal to it; hence the absolute flow-velocity aft of it might still be supersonic, but was directed away from the surface of the aerofoil (or any other body forming an obstacle in the fluid). The result was that, behind the oblique shock-wave formed from a laminar boundary layer, the boundary layer tended to separate from the surface and thicken greatly, while the absolute velocity might still be supersonic. The boundary layer then broke down into the turbulent state, and when this happened, a second shock-wave occurred which was up-right, and behind which the flow was supersonic. The λ-stall was, hence, according to Ackeret's experimental investigations, constituted by an oblique front leg due to laminar boundary layer flow, and a rear up-right leg which was due to the turbulent state in the boundary layer.

Ackeret had established that a turbulent boundary layer always resulted in an up-right compression shock, whatever the means by which the turbulence was introduced. He had also found that, at Mach numbers nearer to the critical value, several small λ-shocks were formed in succession, which, beyond a certain value of the Mach number, united to a single λ-shock of greater intensity. With a turbulent boundary layer, however, at all Mach numbers beyond the critical value, only a single up-right wave front was formed.

These investigations might have a profound influence on further development.

Mr. J. E. P. Dunning (Royal Aircraft Establishment, Associate Fellow): In this country during the war they had had plenty of opportunity to see and inspect German power units from aircraft which had been brought down here, and there was nothing remarkable about those units. Again, when representatives from this country had visited Germany after the war, he did not think they had learned a great deal on the power unit side. He considered that the British engine industry, in the cases of both the ordinary piston engine and the turbine engine, was miles ahead of the Germans in respect of thrust, size and reliability. In the development of power units, British manufacturers had not required expensive equipment. They had produced really sound power units without the use of equipment which only the Government could afford to have, such as wind tunnels.

On the other hand, it had been shown by Mr. Smelt that the Germans had several ideas, one of which was the swept-back wing, and British aerodynamicists were annoyed at not having thought of it. Thus, whereas on the engine side Great Britain had practically nothing to learn from the Germans, on the aerodynamic side they had learned a lot; he wondered whether that could be accounted for by the fact that the German scientists had at their disposal a number of high-speed wind tunnels, whereas British scientists had not? Although it might be thought, at first sight, that in Germany there was lack of co-ordination from above, was it not a fact that results they had obtained in reliable wind tunnels were being used in aircraft designs? Although the swept-back wing was said to have been introduced in 1935, the confirmation of its value was obtained by the work in the tunnels; lacking such tunnels that confirmation could not be obtained.

Dr. F. L. Wattendorf (Wright Field, Dayton, U.S.A., Associate Fellow) *contributed*: He would like to compliment Mr. Smelt for his ability to make order out of chaos. His own experience in Volkenrode and Göttingen last year indicated that the information available was spotty and disconnected.

It was interesting to note that in addition to the Otztal 8-meter 100,000 h.p. sonic wind tunnel which had been partially constructed, the German plans called for the future construction of a second tunnel of the same size, power and speed. Each tunnel was to have been provided with three interchangeable balance and rigging systems to facilitate rapid interchange of test set-ups. In addition to these two large wind tunnels a 30,000 h.p. gas turbine components laboratory was planned at the same site.

Mr. Smelt mentioned that the problem of supersonic diffusers of increased efficiency, such as the Oswatitsch type, would have an important sideline in the design of supersonic wind tunnels. Since the power requirement of supersonic wind tunnels was an item of major importance, he would like to inquire whether the author knew of any application or serious consideration of the incorporation of such improved diffusers in German supersonic wind tunnels?

Mr. H. Davies (Aero Dept., Royal Aircraft Establishment, Associate Fellow) *contributed*: In his remarks on tip-stalling of swept-back wings Mr. Smelt appeared to suggest that the use of sweepforward, on the lines of Ju.287, might provide a feasible solution to the problem. It was of course true that sweepforward would eliminate tip-stalling, but it was worth mentioning that the adverse effect on directional stability at high Mach number on such a design was likely to prove at least as serious a defect as the tip-stalling, quite apart from difficulties with longitudinal stability near the stall, and other disadvantages of sweepforward.

He would also like to refer to the problem of stalling of swept-back wings at high Mach number which was not mentioned in the paper, but which was as important as the low speed stalling problem, particularly in

relation to the design of high altitude jet aircraft. The tip-stall unfortunately still occurred at high Mach number and the usual devices such as leading edge slots, nose flaps, etc., which provided at least a partial cure at low speeds, could not easily be used at high Mach number. This aspect of the problem was inherently much more difficult to solve than at the low speed end, and it would be interesting to hear Mr. Smelt's views on this.

Finally, in relation to Mr. Smelt's remarks on the application of suction to delay compressibility effects, it was perhaps worth pointing out that the improvement mentioned was possible only if a large proportion of the original drag rise was associated with a separation behind the shock-wave. Present evidence suggested that the separation behind the shock-wave on most thin wings was negligible and in these cases no appreciable gain was likely to be obtained by suction.

MR. SMELT'S REPLY TO THE DISCUSSION

Professor von Karman: He had remarked on the gap which existed between German mathematicians and experimentalists. A few of the first-rank mathematicians—Busemann and Schlichting for example—tried to link theory with experiment, but on the whole the link was absent. The theorist was very largely responsible for this state of affairs; his presentation of the results of his work was only very rarely in a form which the experimenter could understand and apply directly.

Schlichting's supersonic aerofoil theory was a good example of a presentation which could be applied directly; and, in fact, in England they used Schlichting's work in 1943, when they were speculating on the possibilities of supersonic flight. They did not at first notice the error in his integration; but as they concluded that at normal aspect ratios of about six the correction to the infinite aspect-ratio theory was very small, they neglected it in most of that early work. It was only when they considered really low aspect ratios that the full theory came into real prominence. It was to the credit of Mr. Robinson in England, and of several workers in the United States, that only a few months after they had heard of the possibilities of sweepback and low aspect ratio for supersonic flight, comprehensive linear theories of the behaviour of such wings were produced.

Several speakers, including the Chairman and Dr. Douglas, had alluded to the excellent conditions in which the German research staffs did their work. It was to be hoped that conditions of research in Germany had impressed those in England who were responsible for the provision of research equipment and facilities.

Dr. Douglas: He had referred to the work which Göthert did at his 9 ft. tunnel to decide on the Reynolds number at which he should work. He agreed that the results were by no means conclusive; he had mentioned in his paper the distressing variation of critical Reynolds numbers obtained by such experiments, as time went on and experience grew.

It was pleasing that Dr. Douglas mentioned the British research, because a very large number of the German conclusions were duplicated in this country with only about one-tenth the number of people and one-tenth of the equipment employed by the Germans. Personally he would have preferred to recount to the Society some of the work of his own group on flight research at high speeds, rather than describe the German work; but the latter is possibly of more general interest.

Mr. Robinson: it was true that Sauer's book omitted reference to several important phases of the German theoretical work. On the other hand, Sauer had a very difficult task in getting together material for his book. Generally, many of the Germans with whom

he had discussed the subject felt that Sauer was something of a charlatan in collecting together under his own name work which was obviously the product of the efforts of other persons. Although the book was extremely valuable for students, its reception among research workers was very mixed for this reason.

With regard to the suggestion that critical Mach number could be regarded as a lower limit, in the sense that they could be certain that no serious change in aeroplane characteristics would occur until it had been exceeded (although giving no guidance on how far they could exceed it), this unfortunately was not always true. On very thick aerofoils, or aerofoils with big camber well away from their optimum incidence, the high pressure gradients were increased by increasing Mach number and a separation could occur well before the critical Mach number, with large drag increase. One of the curves in Fig. 11 of the paper showed this effect. The conclusion that critical Mach number was of little value as a criterion was unavoidable.

Many suggestions for a high-speed criterion to replace the critical Mach number had been put forward, and a few had been mentioned during the discussion. Professor von Karman spoke of the " limiting line "; as far as he was aware there had been no attempt to correlate this with the aerofoil's measured characteristics at high speeds. Mr. Robinson referred to some recent considerations which would lead one to consider only the component Mach number perpendicular to the isobars, and which went some way towards explaining the discrepancy between critical Mach number and experimental results.

Replying to Mr. Robinson's questions on the swept-back wing, the German rule that sweepback effectively delayed the start of compressibility effects from M to $M\sqrt{\sec\phi}$ was merely a neat way of saving that only half the expected gain was obtained. There was, so far as he was aware, no theoretical justification for it. The best shape to make the wing tip was examined in wind tunnel tests, and it was concluded that a tip cut off along the direction of flight was preferable.

He thought Mr. Robinson was correct in saying that the Messerschmitt P.1111 was the most advanced operational aeroplane actually in construction at the end of the war; but it was possible that all these swept-back wing designs represented only a half-way house toward the Lippisch type of aircraft, to which they would ultimately turn for really high-speed aircraft. Designs of the P.1111 type filled a gap between Mach numbers of 0.8 and 0.9; above this, a trend toward lower aspect ratios seemed likely.

Mr. Weyl: The work of Ackeret, in studying the interaction between the shock-wave and the boundary layer, was of extreme value in this field, and every aerodynamicist was agreed that a really good substitute for critical Mach number was only likely to be obtained by studies of this type. Similar work had been done more recently by Liepmann in the United States, with similar conclusions; and it was hoped that such work would be continued.

Mr. Kronfeld: His contribution to the discussion was very valuable as representing some views of the test pilot on this subject of high-speed flight. Although the reports of tip-stalling with swept-back wings were favourable up to the present, their real test would come when they were flown, not by test pilots, but by ordinary pilots with much less than Mr. Kronfeld's experience.

He very rightly stressed the extreme difficulty of the problem of pilot's escape at very high speeds. He mentioned in the paper the work on this point at D.F.S., where a cabin had been designed to be jettisoned by explosive bolts, the pilot escaping later when the speed of the cabin had decreased. The work on ejector seats, such as was fitted to the He.162, was familiar to most designers in Britain now; an interesting sideline to this work was the test made at L.F.A. on the

effect of ejecting a pilot into a high-speed airstream. A man on a seat of this type was launched into the open jet tunnel (Fig. 5); the effects were unpleasant, but not lasting.

Mr. Dunning: His statement that they had not learned a great deal from the Germans on the power unit side might be contested by some of the German workers in the engine field. Certainly on some aspects of gas turbine design—for example, cooled turbine blades and rotary heat interchangers—they had benefited by a lot of pioneer work on the German side; and their rocket work was far ahead of any similar work in this country. On the subject of high-speed aerodynamics, he was doubtful whether their fine equipment was really the major factor in their progress. The fact was that among the German workers in this subject were some of the best in the world; people such as Schlichting, Busemann, Tollmien, very astute theoretical scientists with considerable physical insight. They were international figures before the war, and long before the British reached Germany they anticipated that really big contributions would have been made by them; they were not disappointed.

Dr. F. L. Wattendorf: The original intention at St. Otztal was to build two identical 100,000 h.p. wind tunnels, one for aerodynamic work and the other for power unit development. This was combined into a more economical design of a single tunnel with interchangeable working sections for power unit or aircraft work, each complete with all measuring equipment. Thus construction or static testing could proceed on one rig while tunnel tests were in progress on the other. It was intended, as Dr. Wattendorf described, to construct the second tunnel at some later date, but there was not much belief among the engineers on the project that the second would ever have materialised, and no preparations were being made for it.

It was surprising that no proposal to incorporate an inclined shock diffuser in a supersonic tunnel was ever put forward in Germany, so far as he was aware. It would seem to be an obvious improvement on such large power, very high-speed tunnels as the 80,000 h.p. Kochel project.

Mr. H. Davies: Many of the important problems which ensued from the adoption of large angles of sweepback and sweepforward had been omitted from the paper; partly for lack of space, and partly because the German work was surprisingly inadequate on many of them, and they had in fact been filling in the gaps themselves. The Germans made no adverse comment on the directional stability of the Ju.287 at high speeds, and it was doubtful whether any really serious adverse effects of this kind would arise with sweepforward; the enhanced separation at the wing root, both near the stall and at high Mach numbers, would appear to be the main disadvantage of a swept-forward wing layout.

The tip-stalling of swept-back wings at high Mach numbers, and the resulting deterioration in manœuvrability at high altitudes, could possibly be mitigated by a very large grading of thickness-chord ratio along the span; but the only real solution for really high-speed aircraft with thin wings at all sections would seem to be to follow Lippisch's lead and reduce the aspect ratio.

Although the present idea was that suction at high Mach number eliminated separation, the experiments were not conclusive on this point. In view of the present work of Ackeret and others showing powerful interactions between the shock-wave and the boundary layer, it was by no means certain that suction would be ineffective in the absence of separated flow. For example, if by its application they could replace a normal shock by a λ-shock, a useful gain might be possible at very high speeds where the loss across the shock-wave predominated.

THE ROYAL AERONAUTICAL SOCIETY

The 697th Lecture read before the Society

THE PROBLEMS OF BLIND LANDING

by

H. C. PRITCHARD, B.A., A.F.R.Ae.S.

Mr. Pritchard joined the Royal Aircraft Establishment in 1930 after obtaining a University Mathematics Exhibition and a first-class Honours degree at Oxford. He has been engaged on navigation and aircraft instrument work and is now Superintendent of the Blind Landing Experimental Unit at Martlesham Heath which is composed of staff from the R.A.E. and the Telecommunications Research Establishment. He is an Associate Fellow of the Society.

A MEETING of the Society was held in the lecture hall of the Institute of Civil Engineers, Great George Street, Westminster, London, S.W.1, on Wednesday, 23rd October, 1946, at which a paper was presented by Mr. H. C. Pritchard, B.A., A.F.R.Ae.S., on "The Problems of Blind Landing." In the Chair, the President, Sir Frederick Handley Page.

The President: Mr. Pritchard had joined the Royal Aircraft Establishment in 1930, after obtaining a University Mathematics Exhibition and a first-class Honours Degree at Oxford. He had been engaged on navigation and aircraft instrument work and was now Superintendent of the Blind Landing Experimental Unit at Martlesham Heath, which was composed of staff from the R.A.E. and the Telecommunications Research Establishment.

1. INTRODUCTION

In being honoured by the request to deliver a lecture on " The Problems of Blind Landing," I am set to some extent a task different from that normally presented to the Society's lecturers. In general the results of successful research are presented to you, whereas I am merely asked to outline the problems — with the implication that constructive suggestions for their solution may result. Personally, I feel that this is a most appropriate type of lecture, particularly in regard to a problem which embraces specialist fields in radio and radar, in aerodynamics and aircraft instruments, to an extent that few can claim to be expert in all.

The problem of blind landing can best be discussed after reviewing existing methods of blind approach and proposals now current for solving the landing problem. It is necessary first to remark that the terms "approach" and "landing" are frequently confused in discussing ways of assisting aircraft in poor visibility conditions, the word "landing" frequently being used when "approach" is intended. In general I will use the term "approach" in relation to the aircraft's path down to a height of about 150 ft., and "landing" will imply the manœuvre of bringing the aircraft on to the ground from a height of that order.

2. EXISTING BLIND APPROACH SYSTEMS

2.1. *Historical*

The problem of approach and landing under poor visibility conditions has been with aviation since its earliest days and has been a subject of attention in many countries during the past 20 years. The major initial contributions to the approach problem were made in Germany with the Lorentz approach

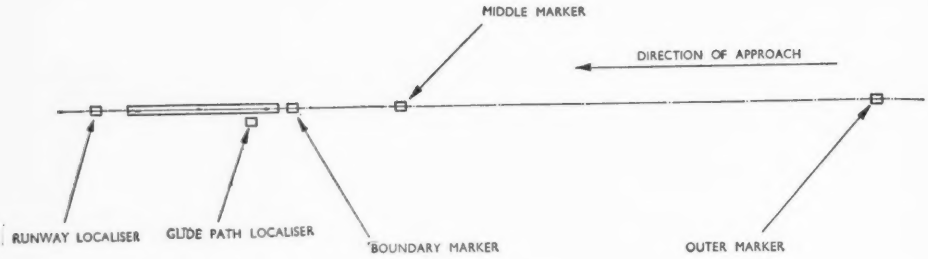


Fig. 1.
SCS51—Airfield Layout.

system, and in the U.S.A., where the work of Diamond and Dunmore in particular has led to appreciable advances.

The Lorentz system is now well-known; an early version was described to the Royal Aeronautical Society in 1934[1], and its practical use was outlined to the Society in 1938[2].

I propose, therefore, to confine my resumé of existing methods to those more recently developed. One of these is in some respects a development of the Lorentz system; the second applies radar principles to determine on the ground the aircraft's position when approaching; and the third, designed in this country during the past war, uses airborne radar equipment. The intention in outlining these schemes is to acquaint those having some knowledge of the earlier systems with the advances which have come into practical use in the past five years, and provide an introduction to later ideas which have not

Fig. 2.
SCS51—Runway Localiser

yet reached an advanced stage of development.

In addition to these systems, mention should be made of other suggestions which have not attained any wide application; magnetic fields for guiding the aircraft, analogous to the marine leader cable scheme, have received some experimental attention; infra-red rays have been proposed; powerful lighting in the visual spectrum has been used; and much work has been done with fog dispersal schemes. I will comment later on such of these proposals as now warrant consideration.

2.2. The C.A.A. and SCS51 Systems

2.2.1. *Introduction*

The C.A.A. system developed for civil airline use in the U.S.A. was engineered in a mobile form normally termed the SCS51 equipment. Some experience of the latter has been obtained in this country, and its main features will be outlined.

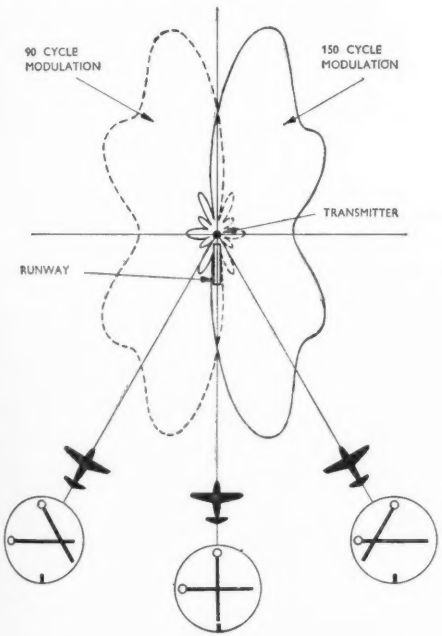


Fig. 3.
SCS51 Runway Localiser—Horizontal Radiation Patterns.

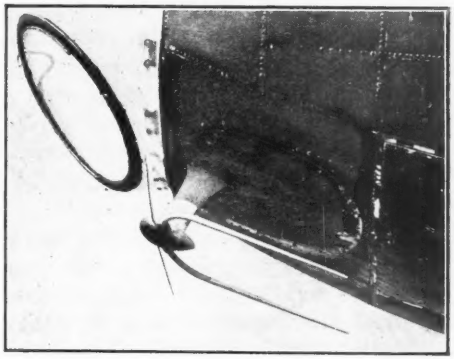


Fig. 4
SCS51—Aircraft Aerial System.

The SCS51 system comprises three main elements on the ground:—

The runway localiser—to provide information on the plan position of the aircraft.

Marker beacons—to indicate distance from the runway.

The glide path localiser—to define the path of the aircraft in the vertical plane.

These are located relative to the runway as shown in Fig. 1, and in the aircraft an aerial system, receiver and indicating instrument are installed.

2.2.2. *The Runway Localiser*

The runway localiser, Fig. 2, radiates two overlapping field patterns as shown in Fig. 3, with a common carrier but modulated, one at 90 cycles per second and one at 150 cycles per second. The runway direction is defined by equality of the amplitudes of the 90 and 150 cycle modulations. The carrier frequency is in the band 108-111 Mc/s., and horizontal polarisation is used.

The modulated patterns shown in Fig. 3 approach maxima at about 6° from the runway direction, and the energy radiated in directions appreciably away from the runway is reduced to minimise unwanted reflections from buildings, trees, and so forth.

The radiation is received by the aerial, Fig. 4, designed and installed to provide omni-directional reception. The aircraft

receiver is a superheterodyne of conventional design, and the 90 and 150 cycle components in the output are separated by band pass filters, rectified, and the difference in the rectified outputs used to actuate a centre zero microammeter, Fig. 5. Full-scale deflection of the normally vertical needle is obtained when the aircraft is more than 3° off the runway centre line. The relation between the current through the meter and the angle made by the line joining the aircraft to the transmitter with the runway direction is linear until this angle exceeds about 3°.

2.2.3. *Glide Path Localiser*

As with the runway localiser, the glide path is defined by two overlapping field patterns, one modulated at 90 and one at 150 cycles per second. The glide path transmitter is located to the side of the runway, near the touch-down point, Fig. 1. Its aerial system comprises one dipole near the ground (1, Fig. 6) radiating a horizontally polarised carrier on about 335 Mc/s. and modulated at 90 cycles per second, with a second dipole (2, Fig. 6) about 15 ft. above the ground and radiating a carrier on the same frequency, but modulated at 150 cycles per second. The radiation pattern from the lower aerial is the large lobe shown in Fig. 7, and is formed by the aerial and its ground image; the upper aerial with its ground image produces the other lobes shown, and the glide path is defined by the intersection of the lowest of these with the lobe modulated at 90 cycles. The intersections of the latter with the other lobes produce paths of angle too steep to give rise to any uncertainty in using the correct glide path.

By adjustment of the heights of the aerials, the angle made by the glide path with the horizontal can be varied from 2° to 5°, 3° being a common setting. The intersection of the two lobes producing the glide path

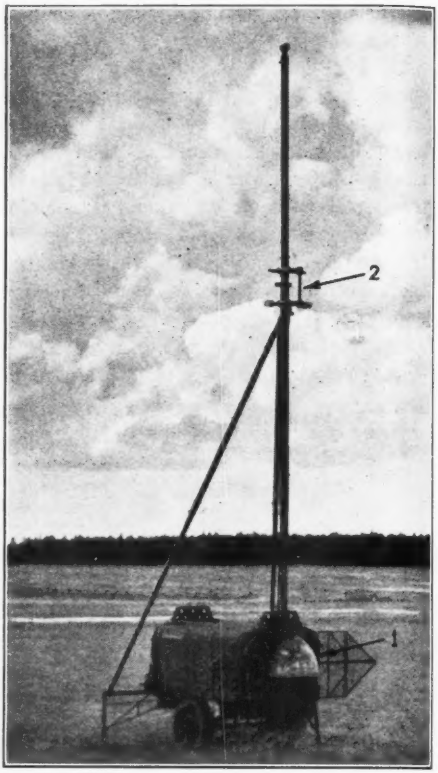
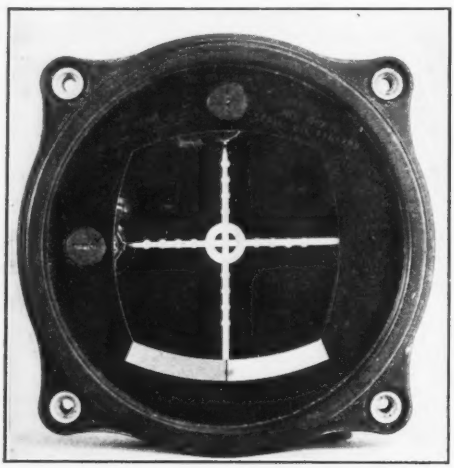


Fig. 6
SCS51—Glide Path Localiser



SCS51—Cross-Pointer Meter
Fig. 5

actually defines a cone with apex at the transmitter; because this is off the runway, the radiation pattern at very low elevation angles has been modified to give an approximately straight line glide path for an aircraft when over the runway.

The glide path radiation is received on a dipole aerial, Fig. 4, and as in the case of the runway localiser, the 90 and 150 cycle modulation frequencies are separated, rectified and applied to the centre zero microammeter, Fig. 5. Full-scale deflection of the normally horizontal needle occurs if the aircraft is 0.6° above or 0.3° below the glide path. The relation between meter current and angular position relative to the glide path is linear up to these values.

2.2.4. *Marker Beacons*

The marker transmitters are installed along the direction of the runway, normally at distances of 200 ft., 4,800 ft. and 4.5 miles from the approach end, Fig. 1. They are modulated respectively at 3,000 cycles per second (unkeyed), 1,300 cycles per second (keyed at 6 dots per second) and 400 cycles per second (keyed at 2 dashes per second). The aircraft normally begins the approach glide at about 1,000 ft. when over the outer marker, and should be at about 50 ft. when the inner marker is reached.

The marker aerial system is a linear horizontal radiator aligned with the runway, and its radiation pattern is narrow in this direction but appreciably broader in a direction at right angles.

The signal received in the aircraft actuates one of three small lamps in the instrument dash-board, depending on which of the markers is being received.

2.2.5. *Comments*

The system is very well engineered, and much development work has gone into the transmission problem to ensure that the approach track defined will not vary with changes in valve characteristics, etc., and into the production of a reliable mechanical modulator. The aircraft equipment is reasonably simple and includes the highly efficient automatic gain control essential for satisfactory operation; the total weight added by the installation is about 65 lb. The aerial system is suitable for many present-day aircraft types.

Generally, the system is a considerable advance on previous schemes, and in particular it provides the first glide path of any

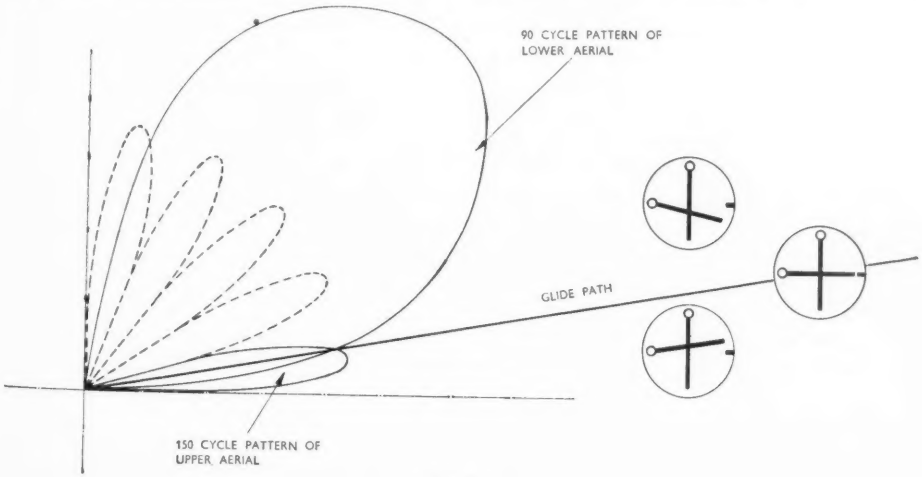


Fig. 7.
SCS51 Glide Path Localiser—Vertical Radiation Patterns.

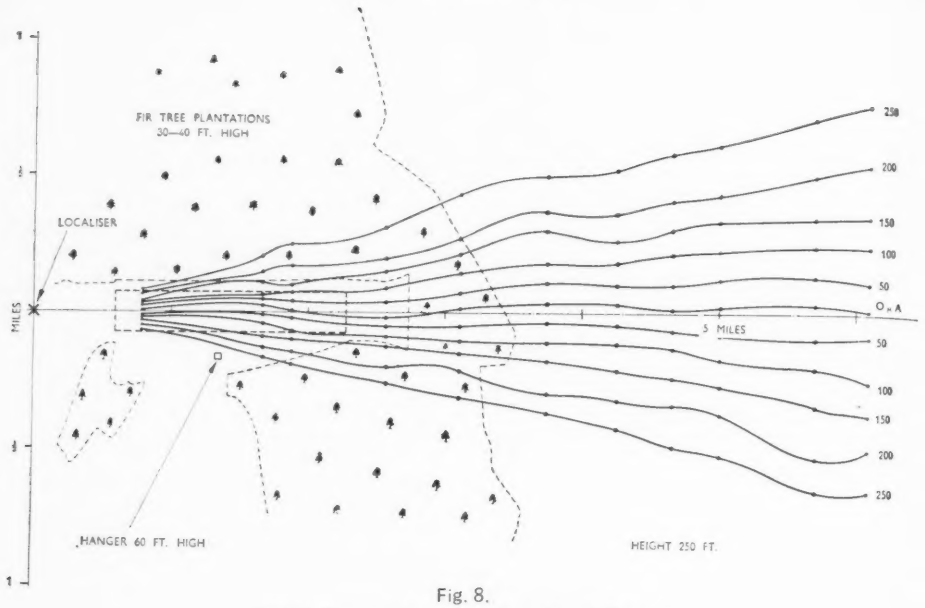


Fig. 8.
SCS51 Runway Localiser—Equi-Signal Curves.

practical importance. There are, however, a number of controversial points, particularly regarding immunity from the effects of reflecting objects. In the case of the runway localiser, although the radiation away from the runway direction is reduced and horizontal polarisation is used to minimise effects from vertical structures, appreciable energy may be reflected from buildings, trees, and so on. A reflecting surface will in general receive different amplitudes of the 90 and 150 cycle modulation signals, which will be partly reflected to the aircraft and superimposed on the wanted signals, so that the difference between the received 90 and 150 cycle signals will be incorrect. The magnitude of such effects cannot be calculated with useful accuracy because the reflection characteristics of buildings and trees are not sufficiently well known, and resource to direct measurement is necessary.

Figure 8 shows equi-signal curves, *i.e.*, lines of constant current through the indicating meter, for an SCS51 localiser installed on a site which was reasonably free of reflecting objects, and which gave a very satisfactory localiser field as judged by experienced flight observers and pilots. The data shown applies to a height of 250 ft. Explorations at 500, 1,000 and 1,500 ft. show similar characteristics, with some decrease in the non-linearity of the equi-signal curves, and the corresponding curves at each height superimpose on each other to an order which confirms that equi-signal planes are substantially vertical.

The results suggest that along the runway direction the position of the aircraft is defined to within about 30 yards, amply accurate for approach to a low height. This order of accuracy has been confirmed by subsequent measurements made over a period of some months from aircraft performing landing approaches, and these results show that deviations of the order of 30 yards may be present for some weeks over a particular stretch of the approach, then disappear for a time, and later re-appear. The cause of such disturbances has not been determined, but the method of measurement used and

the fact that the deviations are predicted quantitatively by experienced observers before measurement has confirmed their presence, leaves little doubt that they do occur.

Generally, it appears that on sites reasonably free of reflecting objects the system gives information on plan position which is amply accurate and smooth for approach to a low height, but which would not be adequate for guiding the aircraft on to a standard runway.

Referring now to the effects of reflecting objects on the glide path beam, no quantitative measurements have yet been made in this country. The radiation patterns depend fundamentally on reflection from the ground, and uniformity of reflection from an area extending a few hundred feet in front of the transmitter is necessary. Variation in the reflection coefficient of this area of ground will alter the angle which the glide path defines with respect to the horizontal; this effect is not, however, likely to be serious, and more important disturbances appear to arise from reflecting objects such as trees and railway lines which provide discontinuities.

It may be noted that the height range covered by the glide path indicator is, when the aircraft is close to the runway, extremely narrow; at a height of 150 ft., for example, full-scale deflection theoretically occurs when the aircraft is only 15 ft. below the glide path.

A further point relating to the system is that a continuous indication of distance from the runway is not provided. The importance of this is at present largely a matter of

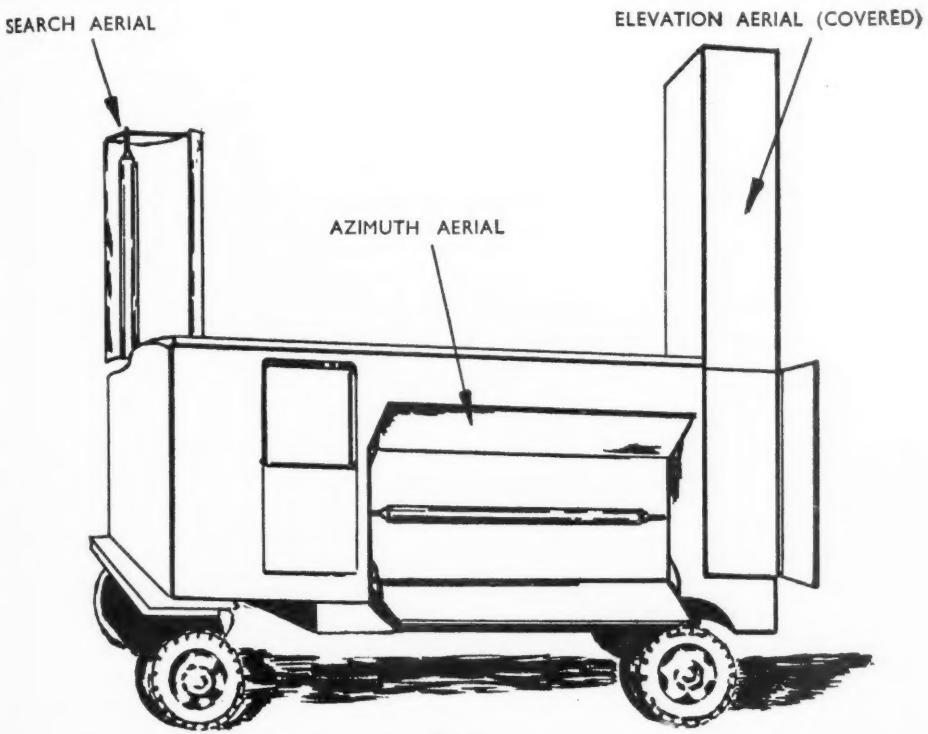


Fig. 9.
Ground-Controlled Approach Equipment.

opinion; it is probably easier to control the aircraft automatically if range is continuously available, and its provision might make possible an improved presentation for the pilot. It cannot, however, be listed as a vital factor for approach control.

2.3. The Ground-Controlled Approach System

2.3.1. *The Approach System*

The ground-controlled approach system comprises a mobile ground radar equipment which determines the position of an aircraft approaching to land, and from this information instructions are transmitted to the pilot so that he can guide his aircraft on to the correct approach path.

The measuring equipment is installed in a van, Fig. 9, usually located some 200 yards from the side of the runway and about halfway along its length. It uses two aerial systems with directional properties, both of which transmit and receive. One is used for range and elevation angle measurement, and the other for determining range and azimuth angle. Each transmits pulses of radiation 0.5 microseconds long, on a wavelength of 3 cm. at a pulse recurrence frequency of 2,000 per second, and receives the resultant radiation reflected by the aircraft; the time delay between the transmitted and the corresponding received pulses is measured and determines the range of the aircraft.

The elevation aerial system consists of a vertical dipole array fed by a leaky wave guide, one side of which is mechanically oscillated to give a cyclic variation of the width of the guide and hence alter the effective wavelength in the guide; as a result the electrical phase at which the dipoles receive energy is varied, causing the beam of radiation directed by a cylindrical reflector to oscillate about a horizontal axis. The angle over which the beam scans is from 6° above to 1° below the horizontal, and the beam is 0.4° wide in elevation and 3° wide in azimuth, the reflector used being 14 ft. high × 2 ft. wide. The beam scans at a frequency of two per second, illuminating the aircraft four times a second.

The azimuth aerial system is similar; it scans through an azimuth angle of 20°, with a beam 0.6° wide in azimuth and 1.5° wide in elevation, using a reflector $8\frac{1}{2}$ ft. long × $3\frac{1}{2}$ ft. high.

In the case of each aerial system, the angular position of the aircraft is defined by the direction of the beam when illuminating the aircraft, and this is determined from the position of the moveable side of the wave guide.

The position of the aircraft is displayed on cathode ray tubes; two are provided for the range and elevation display, one enabling ranges up to 10 miles to be measured, and the other giving more precise information when the aircraft is less than two miles from the ground equipment. Fig. 10(*a*) illustrates the display for the two mile tube; its diameter is 7 in., and on this display the 7° angle through which the beam scans is expanded to 60° to provide increased accuracy of measurement. Range markers at $\frac{1}{2}$-mile intervals, to permit rapid estimation of the aircraft's distance from touch-down, are provided as lines perpendicular to the horizontal time-base. Fig. 10(*b*) shows the range-azimuth display, in which the 20° scan is expanded to 60°, and the position of the transmitter relative to the runway can be seen.

The two range-azimuth displays are viewed by an "Azimuth Tracker," who superimposes on the aircraft's echo a cursor whose movement is measured electrically and used to indicate the position of the aircraft as a lateral deviation in feet from the centre line of the runway. The "tracker" also keeps on the echo a second marker, pivoted about the origin of the time-base sweep, by means of foot pedals which orientate the elevation aerial in azimuth to maintain its beam directed towards the aircraft.

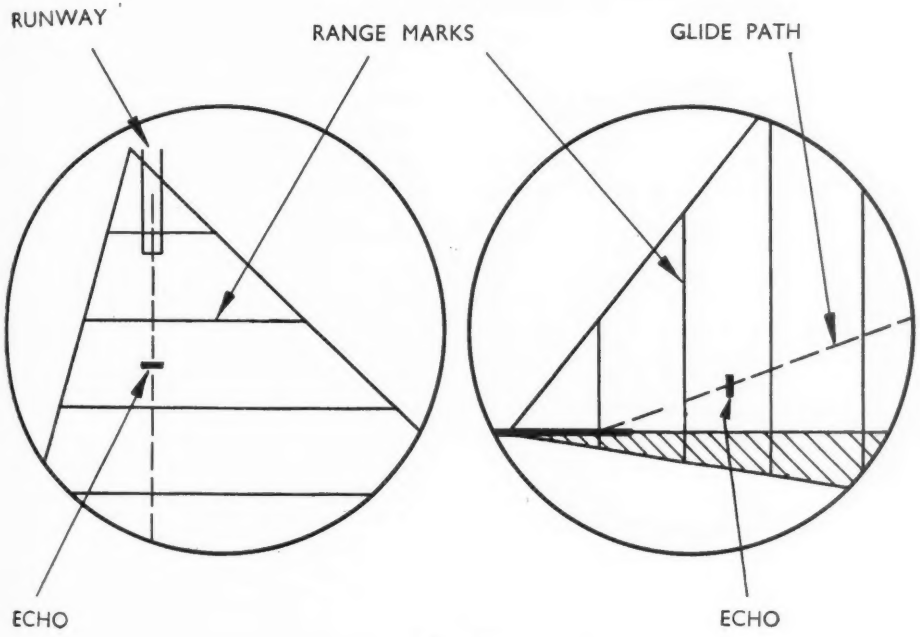


Fig. 10.
(a) Range-elevation Display. (b) Range-azimuth Display.
Ground-Controlled Approach Equipment.

The range-elevation displays are similarly used by a second "tracker," and the distance of the aircraft above or below the pre-determined glide path is measured by his cursor. The information on the aircraft's position is shown on centre-zero meters to a third operator, the Approach Controller, who can view the meters and both the two mile displays. He interprets the displays and meter readings and passes instructions periodically to the pilot, usually by giving the change in heading required, the height above or below the glide path, and the range from touchdown.

2.3.2. *The Search System*

In addition to the approach system outlined above, a G.C.A. equipment normally includes also a search system, which displays on a cathode ray tube the plan position of all aircraft within a range of 15 miles and below about 4,000 ft. in height. This equipment operates on a wavelength of 10 cm., and its aerial system scans continuously through 360°. It is used primarily to give the approximate positions of all aircraft in the vicinity and to enable one to be selected and directed on to the approach track before being taken over by the more precise approach system.

2.3.3. *Comments on G.C.A.*

The G.C.A. system provides some outstanding advantages compared with other existing approach systems; it requires no airborne equipment other than the V.H.F. or H.F. communication set normally carried, and relatively little training is required by the pilot to make successful use of the information passed to him.

Unfortunately, the equipment as at present designed is very costly, and it introduces a limitation which will become more and more serious as air traffic densities increase; the

rate at which aircraft can be handled is limited because only one at a time can be allowed on the approach path, resulting in the landing rate being not more than about 15 per hour.

The system is restricted to assisting aircraft on the approach, because when an aircraft is about to touch-down the elevation beam and its side lobes illuminate ground which is at a range of the same order as the aircraft, and the echo from the latter becomes submerged in ground returns. Further, the accuracy in determination of aircraft height required when landing is unlikely to be achieved by a radar system which must be placed a considerable distance from the touch-down point.

2.4. The Beam Approach Beacon System

2.4.1. *Description*

The beam approach beacon system employs a technique known as "secondary" radar, in which the transmission from the aircraft is received by a ground station, located at the remote end of the runway, and re-radiated to the aircraft. The aircraft transmits pulses which are received by the ground station shown in Fig. 11, and each pulse triggers a transmitter on a slightly different radio frequency after a known short time interval; the radiation comes from one or other of the slots (A-A, Fig. 11) each at a corner of a cavity resonator. These slots are switched at about eight cycles per second by mechanical short circuiting at the centre of the slot. From one a pulse of length five microseconds is radiated; when the other is opened, a longer pulse, 12 microseconds, is transmitted. Thus the radiation patterns shown in Fig. 12 are obtained, and a system in which the relative amplitude of the short and long pulses should remain constant is achieved. The radiation is vertically polarised, the radio frequency is about 200 Mc/s., and the recurrence frequency of the pulses about 500 per second.

The signals received in the aircraft thus comprise a short and a long pulse whose relative amplitude is determined by the angular position of the aircraft relative to the runway centre line. The pulse amplitudes are displayed on a cathode ray tube as depicted in Fig. 13. The distance B-C on the tube is proportional to the range of the aircraft from

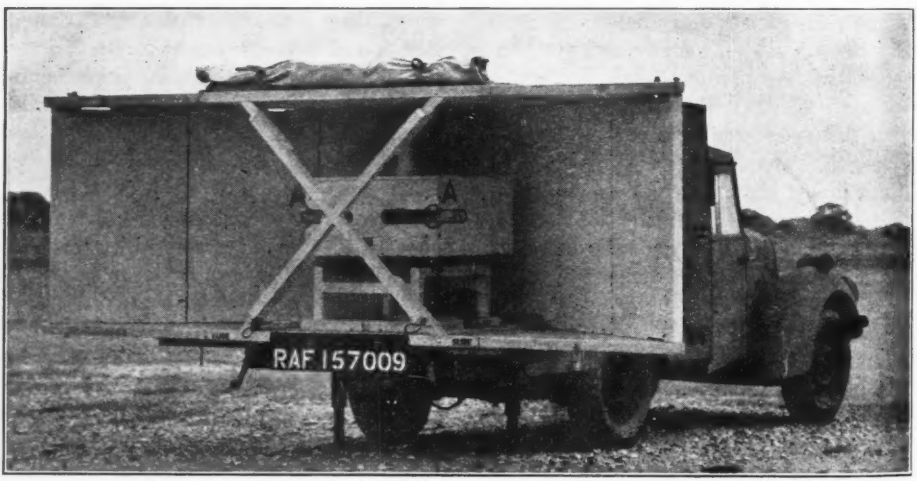


Fig. 11.
Beam Approach Beacon System—Localiser.

touch-down, the indication at B being caused by the pulses transmitted from the aircraft, and those at C by the return pulses; they are displayed along the cathode ray tube time-base with corrections to allow for the time delay at the ground station and for its distance from an assumed touch-down point. The accuracy of range measurement is of the order of 500 ft.

No glide path is provided with the B.A.B.S. system, reliance being placed on the barometric altimeter and the continuous range indication to give vertical guidance. The weight added to the aircraft by the installation is about 120 lb., but it should be remarked that the equipment can also be used for radar beacon navigation aids and that this weight is based on a war-time design which could be miniaturised.

The presentation is normally given to the navigator, who transmits the information to the pilot over the aircraft inter-communication system.

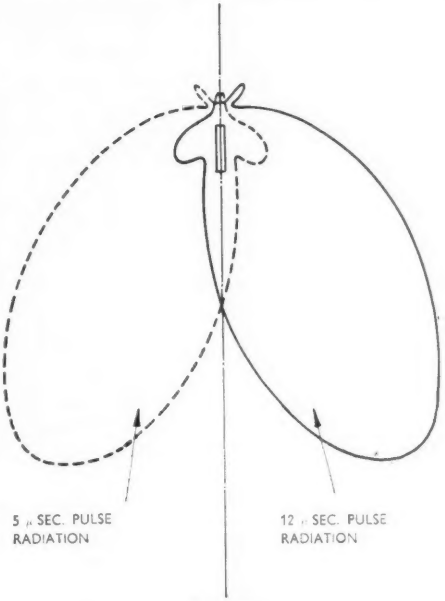


Fig. 12.
Beam Approach Beacon System—Radiation Patterns.

2.4.2. *Comments*

The airborne equipment is complex, and its weight coupled with the presentation of the information to the navigator renders the system in its present stage of development suitable only for large aircraft.

No quantitative measurements of the effects of reflecting objects on its accuracy have been made. It would not be anticipated that the system should be superior to SCS51 in this respect, because the higher frequency and the large amount of energy radiated at about 30° to the runway direction may result in the B.A.B.S. system being more affected than SCS51, although the absence of any back radiation should improve it on some sites.

3. THE FLIGHT CONTROL PROBLEM

3.1. *Introduction*

The difficulties of controlling an aircraft under blind approach conditions are well appreciated; with most systems the pilot, flying at low airspeed and near the ground, must share what little attention can be spared from the normal blind-flying instruments with other dial indications which show his position relative to the runway and his departure from a desired glide path. With modern aircraft even the most highly skilled pilot is severely taxed, probably to such an extent that the margin of safety over human failure is dangerously small. The information given by Dr. E. P. Warner in his 1943 Wilbur Wright lecture[3], that out of 12 fatal accidents during four years of U.S.A. civil airline operation seven occurred with aircraft approaching to land, may well be significant; and it is appropriate to quote the following remarks made by him during the same lecture:—

> " The best present hope of reduction in that considerable proportion of accidents which are ascribable to errors in judgment or in technique does not lie in further improvements in the quality of the personnel concerned, however, but in reducing the difficulties of their task."

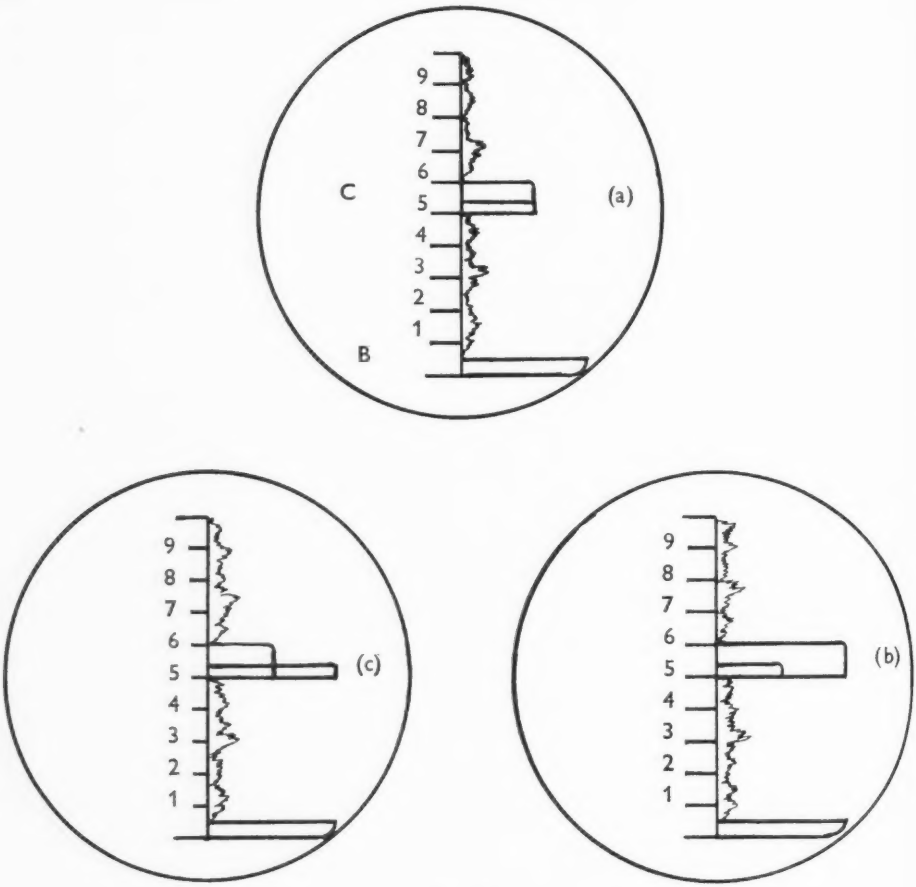


Fig. 13.
Beam Approach Beacon System—Display.
(a) Equi-signal Path. (b) Aircraft 5° to Starboard. (c) Aircraft 5° to Port.

When the problem of landing an aircraft under blind conditions is considered, the pilot's task appears certain to be even more onerous if presentation methods of existing types are used, and in the absence of a presentation which approximates closely to that given under visual conditions, some alternative approach to the problem seems necessary.

The use of an automatic pilot to assist approach and landing has frequently been suggested, but although successful work has been done with pilotless aircraft having simple aerodynamic characteristics, only in recent years has the problem of guiding an aircraft automatically on to a runway been seriously considered.

Automatic pilots have, however, come into considerable use in civil and military aviation to relieve the human pilot's fatigue during long flights, and to a lesser extent to provide very accurate control of the aircraft for, as an example, aerial survey. When automatic controls were first suggested the

initial reaction of most pilots was opposed to their introduction. While this attitude has completely disappeared as regards the use for relieving fatigue, it is re-awakened very strongly if the conception of applying an automatic device to assist the approach and landing is mentioned.

This mistrust has vanished quickly in all cases where the pilot has obtained experience with automatic controls when approaching to land. He realises that there remains plenty for him to do during the approach, thus removing one subconscious prejudice against the automatic aid; he also finds that he can be materially assisted in a difficult task, while retaining effective control of his aircraft because the automatic pilot can be disconnected almost instantaneously if unexpected circumstances, such as danger of collision, arise. However, few pilots have as yet had experience with automatic controls applied to the approach problem, and it is relevant to debate whether the reliability which can be expected from such a device is such that its use should be contemplated.

An automatic pilot consists essentially of a gyroscopic unit and an amplifying or servo device which transforms low power signals derived from the gyroscopes to levels which can operate motors moving the aircraft's control surfaces. The gyroscopes are inherently the least reliable components, being fast running motors with critical bearing clearances. Complete reliance is, however, placed in gyroscopic instruments during blind flying, and provided the automatic pilot as a whole is well engineered its application to blind approach and landing is as reasonable as the accepted use of gyroscopic instruments for blind flying. Further, the adoption of motor-operated control surfaces which appears probable for large aircraft means that the other main units in an automatic pilot system will become an essential component of the aircraft.

Before outlining the problems which arise during automatic approach, a brief description of a modern automatic pilot is desirable; the general principles underlying the application of gyroscopic devices to aircraft control were admirably explained in a lecture[4] which Mr. F. W. Meredith delivered to the Society in 1937, and it is appropriate that I should give the main features of a pilot whose conception and design are due to the more recent work of Mr. Meredith.

3.2. *The Smith Electric Pilot*

The primary function of an automatic pilot is to maintain straight and level flight of an aircraft, and the principle used in the Smith Electric Pilot is that a rate-of-turn of the aircraft about any axis is detected by gyroscopes and a rate of application of the appropriate aircraft control surfaces is initiated to stop the turn.

The gyroscopes used are of the "rate-of-turn" type, *i.e.*, the rotating mass is mounted so that it is free to turn about one axis only, which is orthogonal to the spin axis; hence it can be used to detect a rate-of-turn about the third axis. Three rate gyroscopes are required; one detects rate of pitch and causes elevator to be applied, a second deals with rate of roll and actuates the ailerons, and a third responds to rate of yaw and controls the rudder.

The gyroscopic units are mounted on a platform shown in Fig. 14 which is pivoted about the aircraft's pitch and roll axes and can be rotated about them by small electric motors. The rate-of-turn is detected by an electro-magnetic pick-up associated with each gyroscope, and the signal obtained is amplified and fed to the appropriate control surface motor. Its motion generates a feed-back signal proportional to its rate of rotation which is used to back-off the initiating signal, thus providing a rate of control surface rotation linearly related to the rate-of-turn of the aircraft. A stable system can thereby be achieved, and by adjustment of the magnitude of the feed-back signal, the ratio of the rate of control surface movement

to the rate-of-turn of the aircraft can be varied. This ratio, which is limited by the inertia of the control surface motor system and other sources of time lag, determines to a large extent the precision with which the aircraft can be controlled, particularly at low airspeeds. With the Smith Electric Pilot, ratios approaching four can be used, compared with values of about unity which have been common with earlier types of automatic control.

In addition to its function of maintaining straight and level flight of the aircraft, co-ordinated turns and diving and climbing manœuvres can be made conveniently through the automatic pilot. A Pilot's Controller, Fig. 15, is provided, with an operating handle whose rotation defines the angle of bank of the aircraft, and which imposes a rate of pitch if it is moved in a fore-aft direction.

Rotation of the handle unbalances a potentiometer network controlling the bank motor on the gyroscope platform; the rate of rotation of this platform is detected by the roll gyroscope, and aileron is, therefore, applied to roll the aircraft in a sense which tends to maintain the platform level with respect to space axes. A potentiometer attached to this platform provides a signal

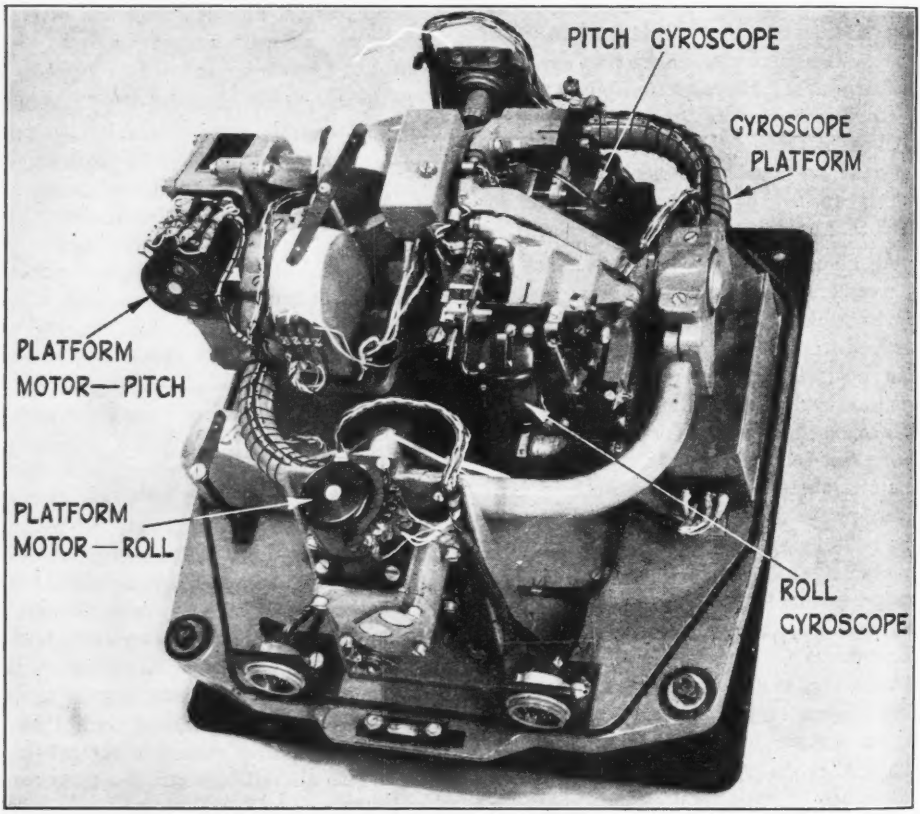


Fig. 14.
Smith Electric Pilot—Gyroscope Unit (cover removed).

which opposes that initiated by the Pilot's Controller, and a state of equilibrium is reached when the signals are equal and the platform is level; the aircraft is then rolled through an angle proportional to the rotation of the operating handle. The motion of the platform relative to the aircraft is also used to feed into the rudder circuit a signal which causes the aircraft to turn at a rate proportional to the bank angle.

The pitch control operates in a somewhat different manner; the pitch potentiometer in the controller is connected to the pitch motor actuating the gyroscope platform so that the latter is turned at a rate determined by the fore-aft displacement of the operating handle. This rate is detected by the pitch gyroscope, resulting in the application of elevator to pitch the aircraft and hence keep the platform level. Thus movement of the handle in the fore-aft direction results in a rate of pitch of the aircraft.

Mention should be made of the gravity and compass monitoring features which are used in the pilot to avoid effects due to imperfections in the gyroscopes, of the sideslip monitor introduced to reduce sideslip during turns at slow speed, and of features which prevent misuse of the pilot; these include provision for taking over control without any disturbance or 'kick' on engagement of the automatic pilot, for preventing engagement until the gyroscopes have run up to speed, and an indicator which shows whether the elevator trim of the aircraft is correctly set.

The pilot is electrically operated, the main supply being required at 115 v. 400 cycles per second, with a small amount of D.C. power at 28 v. The pilot can be adapted conveniently for control by the relatively low-level signals which can be derived from radio systems, by introducing these signals instead of those applied from the Pilot's Controller.

3.3. *Automatic Horizontal Guidance*

Some preliminary experimental work has been done on the automatic approach problem using the SCS51 system in conjunction with an automatic pilot of conventional design.

Fig. 15
Smith Electric Pilot—Pilot's Controller

The SCS51 runway localiser provides a D.C. current which is a measure of the angle between the runway centre line and the line joining the transmitter to the aircraft. This signal may be introduced to the automatic pilot to cause a proportional rate of turn of the aircraft, so that when it is on the centre line no turn signal is present. Such a system would, however, give an unstable approach, for an aircraft initially off the centre line would turn through a continuously increasing angle in approaching it, and would overshoot. This can be prevented by introducing a term related to the rate of approach to the runway centre line in addition to the displacement control discussed. One simple method of doing so is to use the difference between the known runway direction and the aircraft heading as given by a gyro compass.

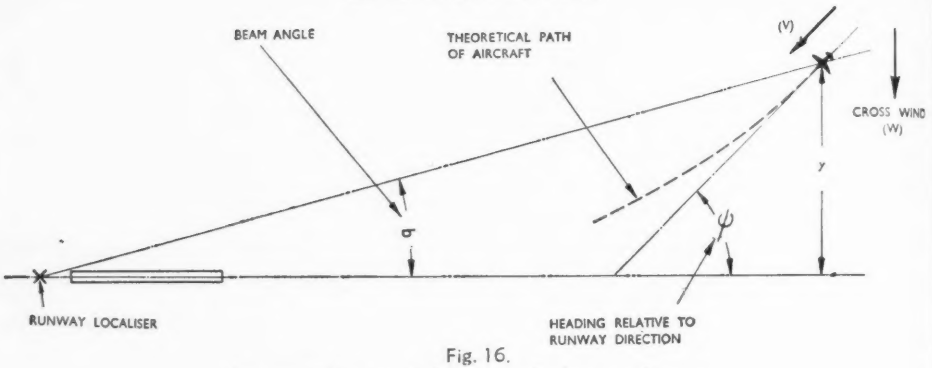


Fig. 16.
Automatic Horizontal Guidance—Explanatory Diagram.

The control equation is then, if aerodynamic and any other lags are neglected

$$\dot{\psi} = a\sigma - b\psi \quad . \quad . \quad . \quad (1)$$

Also, if ψ is small,

$$V\psi + W + y = 0$$

where the notation is given in the explanatory Fig. 16.

These equations give

$$\ddot{\sigma} + \dot{\sigma}\,(2 + bt) + \sigma\,(a + b) + \frac{bW}{V} = 0$$

If the constants a and b are suitably selected, the angle σ will approach asymptotically to the constant value $-\left(\frac{b}{a+b}\right)\frac{W}{V}$

A reasonable value for the ratio $\frac{a}{b}$ found by experiment is about 10, and $\frac{W}{V}$ is roughly the drift angle, so that the aircraft settles on to a downwind approach track which is inclined at about 1/10th of the drift angle to the runway centre line This error can be eliminated by moving the datum from which the aircraft heading is measured at a rate proportional to the beam signal, whenever the aircraft's rate of turn is substantially zero, *i.e.*, by modifying equation (1) to

$$\dot{\psi} = a\sigma - b\,(\psi - \psi_D)$$

$$\dot{\psi}_D = c\,(\psi - \psi_D) \quad \text{whenever} \quad \dot{\psi} \simeq 0$$

where ψ_D is the datum for the aircraft heading, and was originally the runway direction.

A typical approach with this type of control is illustrated in Fig. 17. The approach was started at a range of seven miles from touch-down, the aircraft being about one mile from the runway centre line and heading roughly parallel with it. The aircraft turned rapidly on to the centre line, the maximum change in heading being about 45°; during this manœuvre approximately constant height was maintained, until at the point A engines were throttled and the approach glide began. The aircraft maintained the required track to within about 100 yards, and completed the approach substantially on the centre line.

Analysing the approach in more detail, the drift angle was about 4°, so that the position of the aircraft north of the centre line at the end of the initial turn, and its final heading, are in accordance with theoretical expectations. The northwards departure of the aircraft after starting the glide is due to the large change of rudder trim with throttle setting which occurs on the aircraft concerned, but this effect and other deviations from the theoretical path which can be discerned from detailed examination of the record have been eliminated before the end of the approach. Such departures could not, however, be tolerated if the order of accuracy required for landing on a runway were desired. Consideration of a number of records, similar to that shown and obtained under varying weather conditions, show that

high gearing in the automatic pilot is required to give precise stabilisation and to minimise disturbances due to change of rudder trim with throttle setting and varying airspeed, and that the large variations of cross-wind with height which occasionally occur may prove to be the limiting factor with the particular control system used.

An interesting point is that a scheme similar in many respects to that outlined above was brought into small-scale use by the Germans towards the end of the past war. A beam system of the Lorentz type was used in conjunction with the K.4 automatic rudder control, the pilot manipulating ailerons to give co-ordinated turns; the automatic control provided a higher gearing than that used in the experimental work I have described. It is believed that the system functioned well and brought the aircraft on to a standard runway, except when an appreciable cross-wind was present.

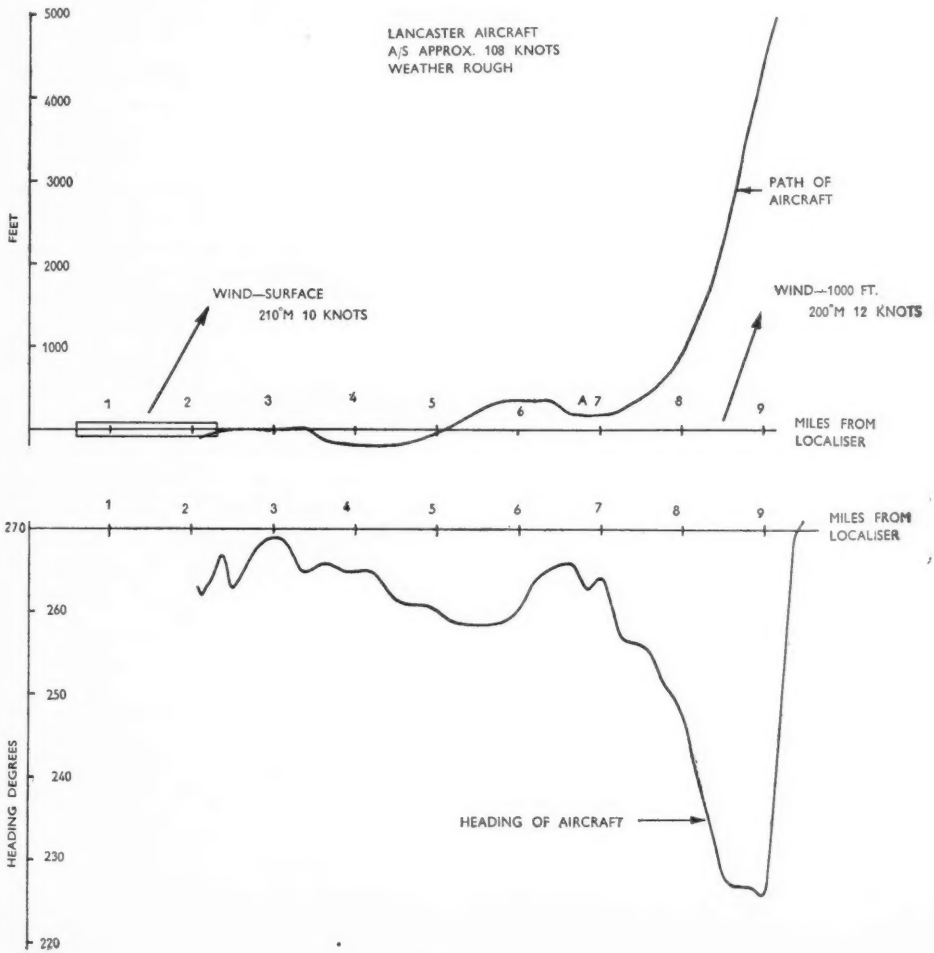


Fig. 17.
Automatic Horizontal Guidance—Typical Approach Path.

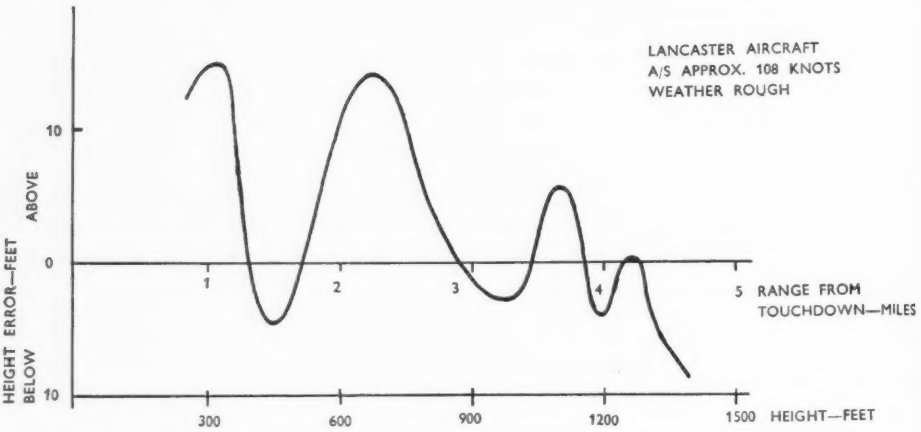


Fig. 18.
Automatic Vertical Guidance—Height Errors.

It should be remarked that the particular control system used represents only one of a number of possible approaches to the problem. In particular, the use of aircraft heading to provide a measure of the rate of approach to the beam may be superseded by deriving the rate term from the beam itself. Given a measure of the aircraft range from the localiser, the linear distance of the aircraft from the runway centre line can be derived from the beam signal, and differentiation with respect to time will provide the rate of approach. The use of this term should minimise errors which arise from variations of cross-wind with height because the rate term is being measured from the correct datum rather than from one which varies with the cross-wind. It does, however, require that as the beam is traversed its signal must vary smoothly so that the rate derived by differentiation is accurate, a condition not adequately met on many sites by any existing beam system.

3.4. *Automatic Vertical Guidance*

The problem of guiding an aircraft in the vertical plane down the required approach glide path appears somewhat easier than the horizontal guidance problem which has been discussed, primarily because the aerodynamic damping in pitch is usually much better than in yaw. This remark applies, however, only to the approach phase, the conditions during the final landing manœuvre being vastly different.

Figure 18 is a typical record showing the accuracy with which an aircraft under automatic control adheres to the required path in the vertical plane. During this approach, throttle and flap settings were constant; the approach speed of 108 knots was maintained by the control to within ± 6 knots.

The elevator was controlled by signals derived from the SCS51 glide path and from the pitch gyroscope of the automatic pilot, so that $\theta - c\beta = 0$, where θ is the pitch attitude of the aircraft relative to a datum displaced 3° (the glide angle) from the vertical gyroscope, β is the angular position of the aircraft relative to the SCS51 glide path, and c is a constant.

This result, while technically promising, is of a preliminary nature only, for experimental work with differing types of aircraft and with variation of flap setting during the approach is required before a final type of control can be established.

4. SOME SUGGESTED METHODS OF POSITION FIXING

4.1. *Introduction*

The methods of fixing the aircraft's position and of controlling it which have been described relate primarily to the approach path and do not apply in general to the final landing manœuvre. The urgency of attempting to deal with this last phase of a journey by air without visual contact with the ground needs some comment, for even in our variable climate conditions approaching zero visibility on the ground are somewhat exceptional.

One's personal observation on this point is perhaps as reasonable a guide as can be obtained without an extensive analysis of meteorological data, provided that two facts are remembered. Firstly, not only must the landing conditions be suitable, but the forecast must also be favourable, and this may well introduce a factor approaching two over the actual incidence of unfavourable conditions. Secondly, conditions at night are in general appreciably worse than in daylight hours.

Meteorological data relating to Southern England suggests that over this area a 600 foot ceiling is four times as frequent as a 150 foot limit, so that a reduction in operating ceiling from 600 feet to 150 feet would be a large step towards eliminating the number of flights cancelled by terminal conditions. I am tempted to hazard the estimate that, while at present terminal conditions are the main unavoidable source of cancelled flights, an operating ceiling of 150-200 feet would leave them at least as large a contributor as any other single cause. In this connection, the average yearly percentage regularity of the U.S.A. internal airlines was 94 per cent. in 1942, with a maximum in summer of 98 per cent., and in winter a minimum of about 88 per cent. Terminal visibility conditions accounted for 70 per cent. of cancelled flights.

Before discussing particular suggestions for fixing an aircraft's position during both approach and landing, it is perhaps necessary to venture some general remarks on the landing problem, for the control of the aircraft during landing will undoubtedly influence considerably the choice of a position fixing system.

It may first be remarked that the conception of a fixed glide path to which the aircraft is controlled down to the ground is frequently advanced. This implies that the aircraft is controlled to impact the runway at a fixed point or on a fixed line across the runway, so that the tolerance of several hundred yards which is utilised in visual landings is thrown away; for this reason alone, the conception of a unique path is not attractive if landing with it is contemplated.

A second suggestion, which has been used in pilotless aircraft work, is that the aircraft should be controlled on a fixed glide path down to a height which, depending on the aircraft type, might be between 20 and 100 feet; at the predetermined height, positional control in the vertical plane is abandoned and gyroscopic control only is used, *e.g.*, the pitch attitude of the aircraft given by a gyroscope might be altered so as to flatten out the path and bring the aircraft to the correct condition at touch down. This conception demands precise control of many factors, such as airspeed, loading, flap position and engine conditions, which may well in their aggregate effect prove to be critical. The thought of leaving the aircraft to a control which is not related to the ground also suggests that a high order of reliability is not inherent in the scheme.

4.2. *Radio Altimeter*

A conception for instrument landing which appears reasonably sound is that the height of the aircraft above runway level should be measured continuously and smoothly so that it can be differentiated, and that the primary control near the ground should depend on

height and vertical velocity. With such information, the aircraft is not confined to a unique path, and can be controlled from all the factors which affect its safety at the moment of impact.

The most promising means for obtaining the height measurement is probably some form of radio altimeter. Altimeters using the heterodyne principle[5] have been used to an appreciable extent, but their accuracy near the ground, of the order of 10 feet in the most suitable equipment now existing, would certainly fail to meet the requirement for landing. A substantial improvement in accuracy can undoubtedly be obtained, for developments in centimetric valve technique make available a more favourable frequency band, and it is possible that an accuracy of about two feet can be obtained.

While such an instrument may prove a valuable adjunct to the landing manœuvre, its application to vertical guidance during approach meets with one awkward obstacle; the ground is often far from level. Since slopes greater than 1 in 20 are common, the altimeter could not provide a usable glide path. The information on ground contours required to correct the altimeter can, of course, be found and it may be that some practicable method of applying it will be forthcoming. If so, the use of a radio altimeter for vertical guidance during approach and landing would become an attractive proposition.

It is of interest in this connection that measurements of manual landings with experienced pilots made by German workers showed that near the ground the height of the aircraft varied exponentially with time to touch-down, *i.e.*, followed the law:

$$\frac{dh}{dt} + kh = 0 \quad . \quad . \quad (2)$$

where h is the height of the aircraft, t is the time in seconds and k a constant of the order of 5, which varies with the type of aircraft.

In the German Fu. G. 101 radio altimeter, the normal indication of height above ground is given by a D.C. milliammeter, and in principle the addition of a condenser-resistance network can be arranged so that no current flows through the meter when equation (2) is satisfied. Thus, if the pilot maintains the needle of the instrument against a fixed mark, the aircraft should follow the required path on to the ground. Considerable success was claimed for this scheme by the Germans as a result of tests under a hood; it was stated that pilots with experience of it kept an eye on the "zero-meter" during visual landings, because they found that improved landings resulted.

4.3. *Narrow Beams*

It was stated in discussing the SCS51 system that the effects of reflecting objects provided a controversial subject, a comment which applies to all existing beam systems. One line of attack to remove this difficulty is in the application of centimetric radiation, made practicable by the advances in valve technique of the past few years.

Radiation on a wave length of, say, 3 cms., can be directed in a beam of angle $\pm 0.5°$ by a reflector of diameter about six feet, and a glide path formed by overlapping beams can then be provided such that the radiation does not impact the ground or illuminate obstructions lower than the 1° elevation angle normally specified for runways.

The runway localiser radiation can also be kept above the 1° elevation angle and restricted in the horizontal plane to, say, $\pm 6°$ from the runway direction.

A system on these lines should give immunity from reflection troubles, and if the runway and glide path localisers are combined in one equipment placed off the landing end of the runway, as shown in Fig. 19, an approach scheme attractive in many respects is presented. As usual, there are, however, some controversial points, such as:

(i) The aircraft must be fed into the runway localiser beam by a precise short-range navigation airfield control system, since the coverage of the beam at 10 miles' range is only two miles.

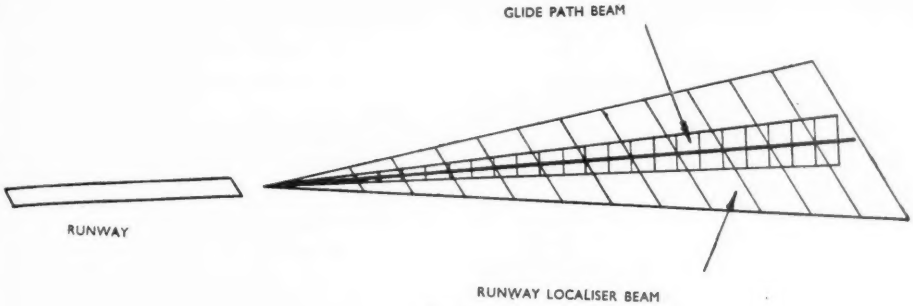


Fig. 19.

(ii) While the system gives in principle complete immunity from reflection troubles, the reflection coefficients on 3 cm. wavelength are appreciably greater than on the wavelengths hitherto used. Suppression of side lobes and generally a well designed reflecting system will be essential.

(iii) The sensitivity of the horizontal guidance indication increases much more rapidly as the runway is approached than when the localiser is at the remote end of the runway.

(iv) If more than one aircraft is in the beam, the one nearest the runway may affect appreciably the radiation reaching the others, owing to the high reflection coefficient on the short wavelength used. The rate of landing may, therefore, be restricted.

If these problems can be surmounted, the use of short wavelength radiation gives promise of a compact ground set and a simple airborne installation, with reduced aerial sizes and lighter equipment than hitherto attained. There appears, however, little hope that it can provide more than an approach system, usable possibly down to a height of the order of 200 feet.

The main advantages of the suggested system over existing aids appear to be:—

(i) Immunity from reflection troubles, enabling the equipment to be used on many airfields where existing beam systems would give poor results.

(ii) Relatively simple and compact ground and airborne equipment, which with (i) will tend to increase the scale of use.

It is apparent that, to provide an appreciable advance compared with existing aids, the pilot's task will need to be lightened by coupling the system to an automatic pilot or providing for him a much improved presentation, for which continuous range measurement used to reduce the sensitivity of control as the runway is approached may be necessary.

4.4. *Leader Cable*

A proposal which has frequently been made for defining the required approach track for an aircraft is the use of a leader cable, as sometimes applied to the problem of assisting ships into harbour during poor visibility conditions. In its simplest conception, the method uses a single cable carrying alternating current, creating a magnetic field which is detected by a horizontally mounted coil in the aircraft. When directly over the cable, *i.e.*, over the runway centre line or its extension, no current is induced; the magnitude and phase of the induced current give a measure of the departure from the centre line.

Many variations of this scheme have been proposed to provide both horizontal and vertical guidance. In the simple case of one cable, the magnitude of the current induced in a vertical coil with its plane fore-aft in the aircraft gives a measure of height pro-

vided the aircraft is directly over the cable. Unfortunately, seriously erroneous information is provided if the aircraft is off the centre line by an amount comparable with its height. It appears that, if schemes involving a multiplicity of cables are used, either the same failing occurs, or the percentage variation of induced current with height is too small to permit sufficiently accurate measurements with reasonable airborne equipment.

The scheme is therefore limited to giving horizontal guidance, for which it has some attractive features when the aircraft is near the ground. Usable signals can be obtained with simple airborne equipment at ranges of 500 feet with cable currents of the order of 30 amps. at 1,000 cycles per second, and a high order of accuracy and reliability could be assured.

The practical aspect of running cables more than, at the most, two miles from the runway appears to prohibit the scheme as an approach aid, and it therefore implies a change from an approach to a landing system at a height of not more than 500 feet, which may well be regarded as undesirable.

4.5. *Radio Camera*

During the war airborne microwave radar was used to provide in the aircraft a map or picture showing the main features, *e.g.*, towns and rivers, of the country below. With the possibility of using waves in the millimetre region to give high definition, the spectacular step forward of providing the pilot with a quasi-optical image of the runway and its surrounds may perhaps be contemplated.

Much research is required before a resolution comparable with ordinary vision can be attained, and it may be that with the wavelengths involved scattering and attenuation will prevent useful results under some atmospheric conditions Also, the weight of equipment using present techniques is prohibitive for airborne use, but here alternative methods may be possible and result in a simple and light device.

Such considerations definitely pertain to the future, but offer a possibility which should not be ignored as research progresses.

4.6. *Sundry Points*

(i) The suggestions outlined above are a selection from many, and were chosen primarily to show that techniques which may solve blind landing are now possible, and to illustrate the problems involved. In the perhaps idealistic aim of achieving a complete solution, the contributions which airfield lighting and Fido can offer have not been detailed, because neither appears likely to deal with all weather conditions.

(ii) The measurement of the range of the aircraft from touch-down during the approach has also not been discussed in detail. Unfortunately, the radar method of range measurement involves weighty and complex aircraft equipment in relation to a function which does not appear of great importance; in other words, range specifically for blind approach must be provided cheaply. It may, however, prove to be the case that range measurement from the aircraft is also desirable, perhaps essential, for airfield control under restricted visibility conditions.

(iii) The form in which the information of his position should be presented to the pilot during manual approach has not been given any prominence. This is the subject of much debate in relation to existing approach systems, but a clearer conception than now available of future methods is required before it can be discussed usefully.

(iv) A general conception which should be borne in mind is to seek as far as possible a common solution to the horizontal guidance and the short-range navigation problems, remembering that the former demands a much higher order of accuracy. It may also be suggested that approach and landing should use the same equipment, not only in order to avoid any change-over at a critical stage, but also so that the use for landing

can come gradually as experience and confidence in the system are obtained.

(v) While the application of the automatic pilot to the approach problem has been considered to some extent, its use during the landing manœuvre has to date received little attention. When discussing this it should be remembered that the aim is not to replace the pilot, but to assist him in a difficult task. Thus it may prove that automatic azimuth guidance only is required, the elevator being left under the pilot's direct control. It may be remarked also that automatic throttle control has not been discussed because it is felt that for psychological and practical reasons throttle operation should be manual.

(vi) A number of points relating to the final stage of a blind landing have not been mentioned. In particular, the necessity for removing drift immediately prior to touchdown in a cross-wind landing may not arise frequently under blind conditions, but it presents a difficult technical problem, and the control of the aircraft on the runway will also need much investigation.

(vii) Attention must continuously be directed towards the effects of trends of aircraft and engine development on the blind approach and landing problems.

With the advent of jet engines, low angle approaches appear likely to come into vogue under all visibility conditions, probably without serious impact on the angles used in blind approach.

The use of tricycle undercarriages will undoubtedly assist the blind landing problem, because of the reduced tendency to balloon after touch down, and also by providing easier runway control.

The effects of aerodynamic developments in the quest for high speed and for low-drag wing sections are, however, much more speculative, since they may react in a manner at present unpredictable on the problems of control at slow speed.

(viii) In tackling the problems of blind landing, one bar to rapid progress is that much flight experimentation is required for varying weather conditions, differing types of aircraft and the vagaries of existing radio fixing systems combine to provide a formidable programme. The extensive use of instrumentation methods is essential in this connection.

It is also important that technicians employed on the work should themselves have piloting experience, in order to gain an appreciation of the difficulties, and to have the best opportunity for proposing methods for their solution.

(ix) International standardisation of a blind landing system will ultimately be necessary; it is too early to discuss the implications.

5. SUMMARY

The problems of blind landing comprise that of defining the aircraft's position relative to the runway, and that of controlling the aircraft from the positional information. The position fixing problem is unlikely to be solved for the purpose of landing solely by beam or ground control systems, such as have been used for blind approach, although a centimetric beam system may lead to an appreciable and worth-while advance for approach purposes.

The provision of adequate information for vertical guidance appears the most difficult landing problem, and some form of radio altimeter the most promising solution.

The use of automatic controls to assist the human pilot in controlling the aircraft on the approach track should ease his task considerably, and the application of this conception to the landing manœuvre deserves investigation.

6. CONCLUDING REMARKS

The title "The Problems of Blind Landing" invites emphasis on the difficulties involved in bringing an aircraft safely on to the ground in zero visibility conditions. My remarks may therefore present a somewhat complex picture, but I would emphasise that

the advances in radio technique and in aircraft control which can now be applied to the problems give every promise of considerable advances over the existing state of the art. The days when blind flying seemed more difficult of achievement than blind landing now appears are within the memory of many.

There is required, however, a clear conception of the lines on which to pursue research and development so that a practicable solution of the problems may be attained.

ACKNOWLEDGEMENTS

I should like, in conclusion, to express my thanks to my colleagues and other workers, from whom will have emanated any conceptions of value which may be found in the lecture.

I should state, however, that all opinions expressed are my own and do not necessarily represent those of the Royal Aircraft Establishment or the Ministry of Supply.

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On the motion of the President, the sincere thanks of the meeting were accorded Mr. Pritchard for his paper.

DISCUSSION

Mr. W. G. A. Perring (Director, Royal Aircraft Establishment, Fellow): He paid tribute to Mr. Pritchard and his team who had been working on the blind landing problem, probably the most important problem that had to be solved in connection with aviation. He regarded the aspect of it with which Mr. Pritchard had dealt in the paper as being only part of a much bigger problem.

The general question of blind landing was part of the whole problem of the control of aircraft to and from an aerodrome. That control had to be exercised, not in the immediate vicinity of an aerodrome which might be regarded as being within a radius of some four or five miles, but over a radius of possibly 200-300 miles. That was an important aspect to which he would return later. The particular point he had in mind was the importance, when controlling traffic, of ensuring that each aeroplane arrived at the aerodrome facing in the right direction and at the right time.

The consideration of control in and around the aerodrome, in all weathers, could be broken down into the following problems. There was the general problem of control of direction, control of the glide path, the problem of landing the aircraft itself when conditions were really bad, and finally, there was the control of the aircraft on the aerodrome. It was important when handling air traffic to handle it rapidly; the clearance of the runway, the necessity for the ground staff being assured that the runway was clear so that the following aircraft could be landed, was an important phase in general operation.

In considering these problems, it was important to bear in mind the international aspect. The author had described equipment which at the moment was drawn largely from American sources. But ultimately, if full use was to be made of the best landing aids they would have to secure common acceptance and those aids would have to be fitted to all airports that British

aircraft would normally use. That meant all the airports of the world.

Further, in connection with the international problem, the general problem of codes and languages would have to be solved.

From the aeroplane designers' point of view, as much of the equipment as possible must be put on the ground. Therefore, the ground-controlled approach system discussed in the paper had many attractions. For example, it made use of radio receiving equipment which the aircraft might normally be expected to carry. It introduced language difficulties, and possibly it would slow up the rate of landings; the author's estimate was that ony 15 aeroplanes per hour could be handled by it, but nevertheless in an emergency, G.C.A. would be a very valuable reserve. He had the feeling that, with the ground-controlled approach systems, augmented possibly by efficient ground lighting, it should be possible to deal with most of the bad weather conditions that were likely to be experienced.

With regard to the technical aspects, the important advances in radar technique had put into their hands the tools required to solve the general problem of approach, and the development of the radio altimeter had probably also put into their hands the tool they required to deal with the actual landing. So that it seemed that they were in sight, perhaps not of the ultimate solution, but of a reasonable solution of the general problem of landing.

The more general adoption of nose wheel undercarriages would help solve the difficulties of drift at touch-down in cross winds. He felt, too that the development of the electrical automatic pilot, described by Mr. Pritchard, coming as it did at this stage, would also make an important contribution. Landing an aircraft under any conditions presented the pilot with a sufficiently difficult task, but in bad weather it set him an almost impossible task unless as much of the work as possible was taken off his hands. The automatic pilot should be used in this way and carry out as many as possible of the duties involved in the approach and landing operations.

His own experiences bore out the truth of the statement that blind landing presented probably the most important problem to be solved in connection with aviation. For example, recently he had left Paris for Amsterdam by air in glorious autumn sunshine. A few miles north of Paris bad weather was encountered, the sky clouded over and rain began to fall. By the time Brussels was reached the pilot was informed that Amsterdam was completely out-of-bounds. Consequently, the aircraft landed at Brussels and remained there for three hours before it could proceed further; then almost another hour was spent over Amsterdam, almost within sight of the aerodrome, awaiting permission to land. That was not a unique experience and it was not necessary for him to point the moral to the story: the importance of facing up to the problems and providing long-range flying control and the aids for bringing aircraft safely to land under all weather conditions.

Mr. M. B. Morgan (Aero. Department, R.A.E., Fellow): He enlarged on the aerodynamic aspect of the problem as affected by size of aircraft. There was a popular impression that, as the size of aircraft increased, its response to control movement became much slower than that of smaller aircraft, and that in consequence a very different technique might be needed for effecting the actual landing. He had rather shared that view until recently, when he and his colleagues had made some calculations covering a range of sizes from about 6,000 lb. all-up weight to about 500,000 lb. all-up weight. The results had surprised him so much that he deemed them worthy of attention: they indicated that, while it was quite true that response was much slower on the large aircraft, the *consequences* of

this slow response in terms of the parameters which really mattered were relatively small.

For example, they had considered the height at which the pilot would need to start holding off the aeroplane in order to touch down with zero rate of descent. That varied extremely slowly with aircraft size, and indeed, it seemed much more sensitive to wing loading than to size. Taking a wing loading of 30 lb./sq. ft. in a 6,000 lb. aeroplane the pilot must start holding off at a height of about 18 ft. from the ground; for a 60,000 lb. aeroplane the height was about 21½ ft.; and for the 500,000 lb. aeroplane that height was increased only to 26 ft. Similarly, with a wing loading of 60 lb./sq. ft., in the case of a 6,000 lb. aeroplane the height at which the pilot must start to hold off was about 37 ft., and for the 500,000 lb. aeroplane that height was only 52 ft.

These figures were, of course, based on certain arbitrary assumptions about the rate of control movement, normal "g," etc., and compared with average piloting technique they might be somewhat on the low side; nevertheless, they were of value in indicating the variation with aircraft size. Again, calculations on the forward distance travelled while correcting a given sideways offset from the runway direction, indicated comparative insensitivity of this quantity to aircraft size.

The results were comforting, as indicating that, if the problem of bringing an aeroplane to earth successfully were solved for the medium-size aeroplane of about 60,000 lb. all-up weight, the technique and apparatus need not be vastly different for the really large aircraft contemplated for the future.

A big problem in that last stage of bringing the aircraft to earth was undoubtedly that of landing with drift, and at present it was difficult technically to see around it in a clear-cut way. It was the problem of bringing the aeroplane in, travelling down the runway and, lastly, swinging the nose round to just the right angle to bring the aeroplane to earth without too much skid. The difficulty was that the cross-wind might be varying all the way down, and a difficult operation must be performed in the last stages very quickly and precisely, otherwise a lot of drift might be picked up in the opposite direction. However, first things must come first, and once the basic problem of landing dead into the wind had been solved, the other problem should prove amenable to treatment.

He emphasised the author's remark concerning the importance of some of the technical men engaged in work of that sort having some piloting experience. In his view it was absolutely vital, because, unless they had an idea of what it felt like to be on one's own in an aeroplane, it was difficult to appreciate fully the information obtained from the pilot second-hand and really to put it into its proper perspective.

Wing-Commander E. E. Vielle (R.A.F. Transport Command): From the point of view of the practical pilot, he suggested that the big consideration facing them at the moment in any flying was that of doing the right things near the ground; there was an urgent need particularly to help the pilots of big aircraft—aircraft such as the Avro York—in holding off their aircraft at the right height and also, in bringing them down the right approach path. That help was needed more urgently in clear weather at the moment than in bad weather. Anyone standing at the end of a runway at any R.A.F. Station would see pilots coming down —no matter how experienced they were— giving bursts of motors on the approach, and finally, just before holding off, giving another burst of motors and plying the controls. That could not be tolerated, and they should tackle that problem first. If they could solve it for landing in clear weather, they should automatically solve it for blind landing.

Querying the author's remark that it was

unlikely that they could use the automatic throttle control, he said the problems in connection with the York during the approach were mainly those of (1) controlling the throttles to keep the airspeed right, (2) the attitude, and (3) coming down the right glide path. If the throttles could be governed automatically to keep the airspeed where it was set on a dial, the problem of landing the aircraft was about halved.

He had flown with automatic throttles in America and they could keep the airspeed even under bumpy conditions, much more steady than could a human pilot. He and his colleagues did not like it at first, but they all came to like it very much as they gained experience.

Again, if every approach could be made similar, so far as the pilot was concerned, they would be doing a lot to help. A glide path localiser was wanted—something like the SCS 51 was ideal—and there was a variety of automatic pilots which, when linked up to a suitable beam, gave approaches down to 50 ft. with very great accuracy; below that it might go haywire! Standardised approaches were practised at night with sector lights, and under those conditions the pilots usually made a very much better approach provided that the wind remained the same. With the glide path fixed in relation to the ground, if the wind changed in strength it meant a new rate of descent and new attitude which usually resulted in bad approaches and landings until the pilot became accustomed to the new conditions.

The point was that the glide path needed to be varied in angle, depending on the wind. If that were done, the pilot would be concerned with two things, *i.e.*, the attitude of the aircraft and the airspeed. If the airspeed were controlled automatically, and if the glide path were varied with the wind, the pilot would have the aircraft in the same attitude for every approach he made; so that the problem became one of altering the attitude at the right height by the right amount.

At present, if the SCS 51 were used and if there were a 30 m.p.h. wind down the runway, a very different type of approach, from the pilot's point of view, had to be made from that made when there was no wind. Thus, with the present systems every approach with a different wind was done in a different attitude.

They wanted a very good automatic pilot. If with that automatic pilot the attitude to the glide path could be set and the aircraft could come down in that attitude, and possibly at a determined height one altered the attitude by a given amount, at the same time probably throttling back, the landing, if originally calculated correctly, would be a good one every time, irrespective of the wind.

Reverting to the point that, if they could solve the landing problem for ordinary weather, they would become accustomed to doing the right thing and would do it in bad weather also, he emphasised again that they must have more instruments to help the pilots to make even a normal landing in an aircraft such as the York. They could not leave it to the pilot's judgment any longer.

Mr. F. W. Meredith (S. Smith and Sons (England) Ltd.): He was a pilot by proxy, being a designer of automatic pilots, and he hoped the expression of his views would not be taken amiss, in spite of the fact that he did not pilot an aeroplane.

First, he did not feel alarmed about the increase of the size of aeroplanes. It had always appeared to him that, the larger the aeroplane, the smaller were the irregularities in the ground in relation to it, so that the ground became relatively smoother. Further, the amount of travel which the aeroplane designer could provide on the undercarriage to absorb the vertical velocity was increased with the increase of size of

the aeroplane. From all points of view the large aeroplane seemed to have a great advantage over the smaller one.

Again, there was nothing frightening about the actual touch-down manœuvre. It had been solved for very small aircraft, such as the Queen Bee, both in this country and in America; and bearing in mind his remarks on the size of aircraft, the problem should be easier in the case of the larger aeroplane with which they were concerned.

The aeroplane designer ought to give every help he could, particularly in regard to the question of cross-wind at the time of touch-down. He was not sure whether he was asking too much in saying that the safe aircraft of the future should have some form of castor action in the undercarriage, whereby a reasonable amount of drift at the moment of touch-down could be tolerated without causing harm. That would ease the problem enormously; but even if it could not be done he did not think it was impracticable, through the agency of the automatic pilot, to make the necessary correction at the last moment.

He gathered from the remarks of Wing-Commander Vielle, in connection with the making of better landings in clear daylight, that he wanted pilots to bring their aircraft down without varying the throttle. He suggested exactly the contrary. It seemed to him that the throttle was provided for the purpose of varying height and that the correct way of bringing an aeroplane accurately to the point of touch-down was to use the elevators to control the attitude and airspeed and the throttle to control height.

He would like to see the problem approached from the point of view of the vertical glide path localiser taking direct control of the throttles. It might be necessary to bring in an inter-coupling to the elevator control of the automatic pilot, to correct any disturbance introduced by the variation of the throttles; but even that might not be necessary if a powerful air-speed monitor were provided in the automatic pilot to keep the airspeed constant.

If the matter were dealt with from that point of view, he believed the aeroplane would approach the glide path beam at an appropriate speed, some 30 or 40 per cent. above stalling speed; the engines would be throttled back, keeping the airspeed constant during the transition, and then the throttles would be automatically governed to keep the right position in the beam until the aeroplane was very close to the ground. The question as to whether the final flattening out signal was by radio altimeter or by mechanical contact of a plumb line with the ground, as in the case of the Queen Bee, did not appear to be very important.

He had been thinking about the blind landing problem since the Fog Landing Panel, of which he had been a member, was set up at the R.A.E. some 15 years ago. It had always seemed to him that there was grave danger, in providing equipment for Fog Landing, that the purpose for which it was provided might be forgotten. The purpose was to get an aeroplane out of trouble, not to provide an excuse for getting it into trouble. The danger was that, when equipment of that kind was provided, operators might say: "Here is manna from Heaven; let us increase the reliability of our schedules, and fly in all weathers." A possible result would be a large increase of the accident rate.

He might be old-fashioned, and he hoped he did not appear to be too pessimistic, but he suggested that the time when blind landing equipment would be used to increase the regularity of schedules should be pushed into the fairly distant future, and that for the time being they should confine themselves to providing equipment that would save lives which, in the absence of such equipment, might be lost through accidents of faulty weather forecasts, and the like.

Mr. R. W. Taylor (Blind Landing Experi-

mental Unit): One of the major points in developing satisfactory position data at all sites, and one of the dangers of the proposed use of narrow beam systems on centimetre wave lengths, was that the use of wave lengths which were small when compared with the object one was trying to detect, gave very much increased reflected energies. He considered it extremely dangerous to assume that they could get more accurate position fixing by moving to very short wave lengths, on the basis that they need only illuminate the part of the sky that was clear of obstructions from the flying point of view.

It might well be that they wanted to go quite the other way and use very much longer wave lengths, in order that the object which might get in the way would provide very little energy to distort the beam. That was particularly true if they attempted to provide azimuth guidance throughout the approach and landing. If they were to attempt to guide an aeroplane accurately after it was on the runway, almost inevitably objects other than the aircraft itself would be illuminated by the system which was providing the guidance. In that case the use of centimetre wave lengths might give rise to even greater difficulties than they had at the moment.

He referred to the use of the radio altimeter, and particularly the points raised by Wing Commander Vielle in connection with varying the glide path angle. Assuming that the difficulty of ground contours could be overcome in some way, *i.e*, assuming for the moment a flat earth, such that a radio altimeter would give a measure of the height of the aircraft above the runway; if then the aeroplane had a knowledge of the time to go to touch-down and could adjust its rate of descent, so that the rate of descent multiplied by the time to go was equal to its present height, a variable glide path was provided. The "time to go" did in fact include the aircraft's airspeed and the wind velocity; so that if a signal could be provided in the aircraft proportional to the time taken to reach touch-down point, so that the aircraft would lose the appropriate height in the appropriate time, then a system was obtained which approached much more nearly the technique used by a human pilot.

He had skated over the problem of ground contours by assuming flat earth, which was certainly not true, as the author had pointed out. That particular problem led him to what was perhaps the specialist's line of least resistance, and that was, what could other specialists do about it? The radio altimeter measured the distance from the aircraft to the ground and at most aerodromes that distance was equal to the height above the runway during, say, the last 1,000 yards of the approach. If, prior to that point, there were some other means of measuring the height with sufficient accuracy, they could still achieve what he believed was the ideal system in vertical guidance, the "time to go" technique.

He had wondered whether the barometric altimeter, for instance, could provide a sufficiently accurate measure of height prior to the last 100 ft. They could then easily imagine the control signal being derived initially from the barometric altimeter and being changed over smoothly to the radio altimeter for the touch-down.

He endorsed Mr. Meredith's remarks on throttle control. He also was not a pilot; but his very early impressions were that, if somebody were looking after the airspeed by controlling the elevators, he would then lower the aircraft by varying the throttle.

Mr. E. T. Jones (A. and A.E.E. Ministry of Supply, Fellow): He recalled the work at Boscombe Down, early in the war, of Wing Commander (now Air Vice-Marshal) Blucke, who had used then the most fully instrumented Anson he had ever seen; it had been used when there was a lot of fog. That work had been very interesting, and he paid tribute to the pioneering spirit of Wing Commander Blucke, who later had given a

tremendous amount of education in blind approach and landing to R.A.F. personnel.

Since then he had not taken great interest in the problem of blind landing until he had read the present paper by Mr. Pritchard, which had prompted him to think about it and to make a suggestion for Mr. Pritchard's consideration. There might be nothing in it at all, but if he thought about it any more he would probably decide to wash it out of his mind.

He had gathered that the most difficult part of the process of blind landing was the descent through the last 50 ft. Submitting his suggestion he illustrated, by means of a sketch, a building very long, very narrow and not very high, resembling somewhat in shape a water tank such as was used for testing model seaplanes. That would be situated at the aerodrome. In the building there would be a "synthetic" aeroplane having an actual pilot inside, who would transmit elevator movements through the automatic pilot to the aeroplane that was to land. On the wall there would be a graph on which was represented the landing path of the aeroplane coming down into the aerodrome.

The position of the "synthetic" aeroplane in the building would be controlled by the path of the aeroplane that was landing. At a certain point the pilot in the building would take over control from the pilot in the aeroplane; he would do that when the aeroplane was at the right height as it was approaching the runway. As the pilot in the synthetic aeroplane moved the stick, so the elevator of the actual aeroplane would be moved and the aeroplane would change its flight path. A shadow indicating the position of the synthetic aeroplane could be thrown on to the graph or chart on the wall of the building. The pilot in the building could land his synthetic aeroplane either by looking ahead as was normally done in good visibility or by making the shadow follow the graph. The main point was that since the path of the synthetic aeroplane was following that of the actual aeroplane the landings of both would coincide.

He appreciated that the instrumental problems were difficult, but he presumed that telemetering of instrument values could be arranged between the aeroplane to be landed and the mechanism controlling the synthetic aeroplane. The height could probably be fed in better by a ground-operated instrument rather than by one operated from the aeroplane. The wind speed could be fed in, and he imagined there was an instrument which would be suitable to give the drift if necessary.

He asked Mr. Pritchard to consider the suggestion for what it was worth.

Air Commodore Frazer: He supported Mr. Meredith's plea that, before adopting devices in their comparative infancy to enable them to land, or to attempt to land, in increasingly difficult circumstances, they should use them as a means of increasing the reliability and the safety with which they could land in the sort of conditions they attempted to-day. In the process of doing that they would automatically disclose the reliability they could place in those instruments, and could fairly judge the extent to which they could increase the difficulties of the circumstances in which they might attempt to land.

From the pilot's point of view he was attracted by the remarks of Wing-Commander Vielle. The basis of the problem was that, when flying in clear weather conditions, one responded to a series of impressions which were totally different from those to which one switched suddenly when conditions changed, as they had done in the course of the flight mentioned by Mr. Perring, from Paris to Amsterdam. It seemed to him that half the trouble was caused by that sudden switching from one type of indication, calling for one series of reactions, to another type of indication calling for another series of reactions.

To that extent he supported Wing-Commander Vielle's view that if they could land aircraft in day-time by the same method as was used at night and in conditions of bad visibility, not only would they give pilots added confidence when they were landing under awkward conditions, but they would give them the advantage of using the same technique and therefore avoid that strangeness which came when changing from a technique which was normal, to one which was used on only a limited number of occasions.

Mr. W. J. Richards (Chief Superintendent, Telecommunications Research Establishment): There was no doubt whatsoever that the problem of the approach and blind landing would ultimately be solved largely by automatic means, for the obvious reason that that was the only way in which they could rid the human pilot of an essentially difficult task and, as Air Commodore Frazer and others had said, such means offered the only likely assurance that the system decided upon would be used universally, and not merely in conditions of emergency.

As to the types of systems which were likely to provide solutions, they were more likely to solve the problem by means which enabled the aircraft itself to check its position in relation to its desired path than by ground-controlled systems. He would not be rash enough to say whether the system within the aircraft should be by beams, or by altimeter, or other means; but the fitting of the equipment within the aircraft itself was fundamentally sound.

A point which had not been mentioned in discussion, but which he thought was brought out very clearly in the paper, was that there did not, in fact, exist at the moment a really satisfactory system of blind approach which was usable under all conditions and at all times. There was a slight danger of prejudicing the provision of a really first-class system of approach by seeking an ideal *complete* landing system.

Mr. I. Bowen (D.Inst.R.D. Ministry of Supply, Fellow): The object of all the work on blind landing, and ultimately automatic blind landing, must be to enable aircraft to operate fully to schedule, and without disappointment to the passengers. They could approach that ideal by improving their means of getting out of trouble as Mr. Meredith had suggested; but they could get out of trouble in ways which were uncomfortable and which were not economical for aircraft. The object must be to develop a *safe* system and operate an uninterrupted schedule.

The paper, and indeed the author's whole approach to the problem, emphasised the fact that before real progress could be made towards achieving fully automatic blind landing a thorough research must be made into the numerous factors which went to buiding up the complete problem. Such factors as flying characteristics during a controlled approach, the characteristics of the flattening out to touch-down, the nature of radio beam systems, and the desirable characteristics of automatic pilot systems, were now receiving close and co-ordinated study, while at the same time new equipment was being designed and built.

Radio and radar had given them during the past few years valuable navigational and blind flying and landing aids, but the existence of those aids should not lead them to assume that the fully automatic landing was just around the corner. Instruments might come into use—the SCS 51, for example—without their having a really detailed knowledge of their limitations. The grand work which Mr. Pritchard and his team were doing would tell them the limitations of such devices, so that they might know how to improve and apply them in reaching the ultimate goal of automatic blind landing.

He was glad to hear the author air the old controversy as to whether the pilot would be willing to submit to automatic control,

e.g., to an automatic pilot, during the approach; it would be noted that the author's experience showed that mistrust on the part of the pilot rapidly diminished with experience in blind landing experiments. Had he made that point five years ago, probably every uniformed speaker would have howled down the suggestion to hand over the aircraft to control by the automatic pilot; yet, of those who had spoken on the present occasion, none seemed to object. That represented a very great psychological advance during the past five years or so.

The new Smith Electric Pilot was designed *ab initio* with blind landing in mind; it was good planning that had led Smith's Aircraft Instruments to produce the unit in its present form and at this present time. Experience with that automatic pilot at the R.A.E. had furnished increasing confidence that its principles and design were sound and that it would rapidly supplant earlier British and foreign automatic pilots in British and possibly, European-built aircraft. In the present economic and aeronautical position of this country they should give encouragement to such ventures, since great courage had been shown by the Company, and Mr. Meredith in particular, in launching into that very expensive development and bringing it to the stage at which the Company had planned production sufficient to satisfy the needs of civil aviation over the years 1947 and 1948.

He hoped that in the not too distant future the Society might hear Mr. Pritchard describe an accomplished system of automatic blind landing as the outcome of his present work and that of his colleagues at the Ministry of Supply's Blind Landing Experimental Unit.

Mr. N. E. Rowe (Controller of Research and Long Term Development, British European Airways, Fellow): One of the great difficulties in the whole of the work discussed was in the fundamental approach to it, as had been mentioned by Mr. Richards and also, in passing, by Mr. Perring; whether the aircraft should be controlled from the ground or whether the pilot should be given all possible information to enable him to make his decisions on the spot. That was an extremely important matter, and one that ought to be decided early, because it would settle very clearly the directions in which the most intensive effort should be applied. He was no pilot, but his own predilection was for a system which would give the pilot the fullest possible information, and would remove much of the difficulty and leave him as free as possible to concentrate on the actual problems of a very difficult operation, made more difficult by the fact that he was performing it under blind conditions.

Another important matter mentioned by Mr. Richards was that of separating the problem into the approach and the actual touch-down. There was no doubt that assistance was needed as quickly as it could be obtained if they were to make the fullest use of civil aviation, especially in the European area. They were much more concerned with the problem in the European area than were the Americans in their area, because so often in Europe they had to endure flying conditions which they would refer to as blind flying. If they were really to have the confidence of the public in travelling by air, and especially to provide reliable schedules, the equipment could not be made available too soon. Hence if the approach problem, to a height of say 50 ft., could be solved more readily than the whole problem, including touch-down, let them concentrate on getting into use the equipment for the approach and let the touch-down equipment follow later.

The complexities of the equipment, its weight and drag needed careful attention during its development. The aircraft designer and the aircraft operator wanted something as simple and as light and drag-free as could possibly be obtained.

The point made by the author, that the

development of the equipment should take account of the trends of aircraft design, was extremely important in a long-range activity of this sort, where design was changing, wing loads were increasing, different sorts of power plant were being used, and so on. Conversely, the aircraft designer should keep in the closest touch with the work in the development stage of the blind landing equipment, to see how he could help and how the development of the equipment was likely to affect his own designs. Thus, it was a two-way business. A minor point which was obviously of importance was the difficulty due to trim changes when the throttle was altered or when flaps were put down, and so on.

When in America recently, he was told briefly of the sort of arrangement on which the Americans were working. He believed the controversy still existed there as to whether the pilot should have full information and act upon it, or whether he should be told from the ground what to do. But the general trend of opinion seemed to be to give the pilot full information and to take the task off his hands by automatic control as much as possible. The scheme envisaged there, was that by radar means a picture of all the aircraft in the locality in certain height bands would be displayed on a screen in the control room; that would be re-radiated to aircraft in the vicinity, and they would recognise their particular points on the picture by means which were worked out. Also the direction in which the aircraft was heading at the moment would be indicated, and the ground controller would have the ability to mark on a transparent sheet over the display any change of direction which he, by looking at the whole picture, at all heights, would think necessary for any given aircraft in making its final approach. That had been sponsored by the C.A.A. in America, he believed; they were getting good results experimentally and they believed they could make it a practical scheme.

The author had referred to a land line scheme which, by means of a magnetic field, would give information to an aircraft approaching, and to the importance of the radio altimeter. Could those two ideas be combined, so that a sort of land line could be put out, perhaps not necessarily a line, but something which would give an echo to the radio altimeter and thus smooth out the irregularities of the ground before the aeroplane reached the approach area? It might appear to be a wild idea, but he put it forward for what it was worth.

Brig.-General Sir H. Osborne Mance, K.B.E., C.B., C.M.G., D.S.O. (Companion) *contributed*: As a humble passenger he listened to the paper and discussion with great interest. Ultimately they were not concerned with how blind landing was achieved but with the regularity of the service on the one hand and accident statistics on the other.

The psychological reaction of the passenger on an aeroplane which had been making successive banking turns in blind flying for some half-hour after the due time of arrival would, he imagined, be the same whether he knew that the difficult problem of landing depended on the skill and reactions of the pilot or on the aerodrome control. The knowledge that the operation was controlled, if not carried out, by well-proved automatic scientific processes would undoubtedly add to the passenger's confidence; especially if, as suggested in the discussion, the same process was habitually employed for all landings.

Captain J. Dolezal (Associate) *contributed*: It had been most gratifying to hear about the efforts to solve the problems of blind approach and landing and thus enable aircraft to operate in any sort of weather. Unfortunately, so far they had heard very few opinions on this subject from the actual users of blind approach systems as at present in use, namely, the pilots themselves. Therefore, he ventured to mention a few points which, scientifically developed,

he thought might help aircrews in the difficult task of bringing the aircraft in to land in bad weather conditions.

The systems as described during the lecture might be considered in principle satisfactory for blind approach and would probably form a sound basis for future development. There was, however, one big objection; that was that in present form they were taxing the pilot's resources and skill to a very high limit, thus leaving only a very narrow margin of safety.

With the blind approach instruments as they knew them to-day, a lot of good judgment and mental calculation was required from the pilot to form a precise picture of the situation. If they could arrange the blind approach instruments in such a way as to give the pilot a *clear* picture of the situation in terms he was familiar with, then his task already would have been made at least 50 per cent easier.

It was difficult to imagine that at present a good approximation to the day landing could be achieved instrumentally. Yet they were quite at ease and confident when landing at night, even without the outer "drive" lighting. In this case the position of the aircraft, besides height, was defined by a relative bearing and distance from the touch-down end of the runway, while circling the aerodrome during the approach, and then by the yellow, green or red light beams from the glide path indicator and the distance from touch-down point, while the aim was corrected by considering the deviation from the direction of the runway projected towards the aircraft.

Thus by analogy, they came to the suggestion of an instrument which, in miniature, would give the pilot exactly the same picture of the situation. That meant an instrument, giving him (visually of course) the relative bearing and distance while flying around the aerodrome and which, when the aircraft was flying down the beam during approach, would provide the pilot with an indication *where he was* relative to the beam; show his glide path by yellow, green or red light, and give the distance from touch-down point. At the same time, while flying along the beam, by comparison with his relative bearing he should be able to check on his drift, which eventually could be precalculated (N.B. — before using blind approach indicator, directional gyro should be set to zero on a heading parallel to the direction of landing).

He had stressed the words "where he was." In his opinion this was the correct way of indication, since it was on the same basis as all other blind flying instruments and thus *one* method of interpretation would apply to *all* instruments the pilot was using during blind approach. Also the pilot had a better indication *psychologically* of the effectiveness of his corrections, seeing the error to diminish in the *same* sense as he was turning. Thus the pilot would be provided with all the necessary information and what was more, in a way with which he was familiar.

Constant indication of distance during approach, besides having other advantages, was also a great help in proper timing of the cockpit drill. Radio altimeter in the form mentioned in the lecture (Fu.G.101) should prove a valuable help in the final stages even if in the end the actual landing was accomplished visually. It was also absolutely essential to place the blind approach instrument so that it could be read in the closest co-ordination with the blind flying instruments.

An instrument of this kind could also be used to advantage when, upon arrival over the aerodrome, the aircraft had to await its turn for landing. With the ever-increasing frequency of traffic this was almost unavoidable, even when a long-range traffic control was applied most effectively. When flying blind it was not an easy task to keep within a radius of say 5-8 miles from the aerodrome, especially when wind speeds up to 50 m.p.h

might be encountered. The blind approach instrument of a kind visualised above (with a maximum range 10 miles) might be a valuable help and save the pilot much fatigue, since it would enable him to fly comfortably any pattern he liked within the range of his instrument and thus conserve his energy for the final approach and landing.

A properly developed instrument of this kind need not be much heavier than the existing B.A.B.S. and even so, when human lives were the counterbalance, these few extra pounds of apparatus were more than justified.

The introduction of automatically-controlled blind approach and landing seemed to be the ultimate solution of the problem. In the meantime, development of instruments on the above lines might help them to land aircraft in bad weather with a much greater margin of safety.

Mr. L. H. Clough (Associate Fellow) *contributed*: Would Mr. Pritchard explain in detail how the SCS 51 field pattern curves shown in Fig. 8 were taken? In particular he would like to know what steps were taken to eliminate aircraft attitude errors.

It appeared from an examination of the curves that they were most likely to have been taken by an aircraft flying backwards and forwards across the equi-signal track at right angles to the runway and at a fixed speed so that distances could be timed instead of being taken from ground pilots.

(If this was correct the aircraft would of course face opposite ways on alternate runs and in no case would the reading be taken with the aircraft heading for the beacon.)

It would be interesting to hear if any attempt had been made to compare the field pattern obtained by a flight in the reverse direction to that used for Fig. 8 using the same landmarks.

Alternatively, in the apparently unlikely event of the flight having been made along equi-signal lines instead of across them, how had aircraft and pilots response errors been eliminated?

Finally had any change of equi-signal line been detected anywhere in the field due to banking the aircraft?

Mr. R. Ashton (Associate Fellow) *contributed*: His first reaction to the lecture was one of disappointment; as other speakers expressed their views his reaction became one of dismay as he realised how little the problem of approach and blind landing was understood.

From his own 24 years of experience in the flying world, he stated with the greatest possible emphasis that what had been done and was being done to provide aids to blind approach and landing was totally inadequate; he found these views were shared by many well-known pilots.

Fundamentally the problem was as follows:—

(1) The system to be used must operate in zero visibility and cloud base at ground level.

(2) The system must be able to handle landings at the rate of at least 48 per hour.

(3) The associated ground system must be able to clear the runways to the parking area at a rate at least equal to the landing rate.

Certain other subsidiary points were:—

(*a*) There must be an efficient approach system to the controlled area such as the Decca system.

(*b*) Flight plan must be made so as to enter the controlled area boundary at a prescribed time.

(*c*) Orbitting must be prohibited.

(*d*) The same system for the whole flight must be used in all types of weather.

(*e*) All systems must be fundamentally safe and must be trouble preventers and not systems to rescue the pilot when in trouble.

He suggested that the problems to be solved were:—

(i) The approach to the controlled area and arrival at a predetermined point at a selected time (already solved by present day navigation aids and by accurate flight planning).

(ii) The pilot to select the best power glide to suit the loaded weight and the weather conditions (solved by present day operational technique).

(iii) The pilot to engage the automatic pilot to maintain the power glide (solved by present day instruments).

(iv) The ground control to locate the aircraft on the glide path and tie in the automatic pilot with the glide path. (To be solved and would call for multiple glide path indicators.)

(v) Accurate indication of height, direction relative to a runway centre and distance from the runway end. (Not yet adequately solved.)

(vi) Automatic holding-off passed through the automatic pilot with over-ride left to the pilot. (Not yet adequately solved.)

(vii) Obstruction warning in time to open up and clear the obstruction. (Not yet adequately solved.)

(viii) Automatic pick-up of ground control to the parking area. (Not yet solved but leader cable seems a probable solution.)

(ix) From many angles it seemed that the large aerodrome was going to present many difficulties. Would many of the problems relating to surface reflection be less over the sea?

It might appear that what he had asked for was too much and represented an ideal, but he felt that nothing less was good enough and he would point out that from the beginning of man's attempt to fly each succeeding year had shown that their thoughts and schemes had always been too small.

MR. PRITCHARD'S REPLY TO THE DISCUSSION

Dealing first with the points raised by a number of speakers; the importance of using any blind landing method in good, as well as bad, conditions had been stressed both by pilots and passengers, and the importance of testing any system thoroughly was admirably expressed by Air Commodore Frazer. This led to the conclusion that a system must be devised which pilots would use under both circumstances; to achieve this, it was probably essential for it to provide advantages over the approach and landing method now employed in good visibility. The German radio altimeter scheme was claimed to do so, and Wing Commander Vielle's remarks suggested that a properly conceived glide path—such as that proposed by Mr. Taylor—would also assist the pilot under visual conditions. If, in addition, the automatic pilot provided advantages compared with manual control, the widespread operational use which would result should lead naturally to the ultimate aim expressed by Mr. Bowen—that of providing safe, uninterrupted schedules under all conditions.

Another point which received considerable attention in the discussion was the choice between ground measuring systems and methods which enabled the aircraft to determine its position in relation to its desired path. The former undoubtedly offered considerable attractions as an insurance—it enabled resources on the ground to be brought into action if anything went wrong with the aircraft equipment. However, it was doubtful whether it would give the ultimate answer; it restricted the landing rate, appeared unlikely to give the accuracy required for the final landing manœuvre, and involved more difficulties as regards international standardisation than any other system.

Mr. Perring: While blind landing was part of the general problem of navigation and control of aircraft from one airfield to another, it presented the greatest technical difficulties, and one line of attack had been to seek a solution to the blind landing problem and then try to fit it in with the navigation requirement in order to economise in airborne equipment.

Regarding the international aspect; the use of a radio altimeter for vertical guidance, instead of systems requiring ground installations, might make international agreement easier for that part of the problem; as regards horizontal guidance, it appeared certain to involve ground installations, and international standardisation seemed likely to involve considerable difficulties.

Mr. Morgan: The information on the effects of size and wing loading on the heights at which the hold-off should be commenced was most interesting. Some preliminary recordings of the motion and attitude of aircraft during the landing manœuvre suggested that the pilot normally started the hold-off at a greater height than Mr. Morgan's figures indicated. In the case of an aircraft of 30,000 lb. and 38 lb./sq. ft. wing loading the height was about 50 ft. when landing from a glide giving 1,100 ft./min. rate of descent, and about 23 ft. from a rate of descent of 500 ft./min.; Mr. Morgan's figures related to a rate of descent about half-way between those two values.

The problem of removing drift immediately prior to touch-down in a cross-wind landing had received little attention. In guiding the aircraft down to the runway, a reasonably good measure of the drift angle was obtained and, given an accurate indication of height when close to the ground, it should be possible to apply rudder at the correct instant and head the aircraft into the runway direction. The problem thus provided a further reason for requiring an accurate measure of height when near the ground.

Wing Commander Vielle: The type of glide path wanted, in which the angle was correctly varied with the wind, was provided by the radio altimeter and " time to go " system suggested by Mr. Taylor. Given this, all approaches on a given type of aircraft would be made with substantially the same throttle setting, and large changes during the approach should not be necessary. If the airspeed was near to or below the value corresponding to maximum L/D, the airspeed should be controlled from the elevators and the rate of descent from the throttles, but this might not be important at the airspeeds used under blind conditions, and the argument might also be affected if the flap setting was changed during the approach, because the immediate variation in rate of descent called for an unwanted change in throttle setting. However, since an automatic pilot operating the elevators was provided, and automatic throttle control meant considerable additional aircraft equipment, it seemed reasonable in any case to consider leaving the throttles under manual control—the aim was to assist, but not replace, the human pilot.

Mr. Meredith: The vertical velocities which large aircraft could withstand were usually about the same as for smaller types; presumably they could be increased, but only at the expense of additional weight. The difficulty of landing varied so much between different types of aircraft that size was probably not the major factor and it was difficult to agree that the large aircraft had a great advantage over the smaller ones.

As indicated in the reply to Wing Commander Vielle, the conception of controlling airspeed by the elevators and the vertical path by the throttle was interesting. Regarding the final landing manœuvre, the height of starting it with aircraft having high wing loading, and the desirability of having continuous height information down to the ground, suggested that a radio altimeter would be preferable to the mechanical scheme used with the Queen Bee.

Mr. Taylor: It was agreed that beams

employing centimetre wave lengths would not give more than an approach system, and for that some difficulties might arise, as indicated in the paper. The longer wave lengths suggested introduced difficulties with the large aerial arrays required to produce directional radiation patterns, and also it appeared almost impossible to predict whether a beam system which illuminated obstructions would be satisfactory on all sites.

Regarding the suggestion of using a barometric altimeter during the approach, existing types could not be relied upon near the ground. Errors of the order of 100 ft. occurred due to hysteresis effects, and even if special altimeters were developed these effects and others due to variation of position error were likely to give errors up to 50 ft. This suggested that even an improved barometric altimeter could not be used safely below about 200 ft., since at that height a 50 ft. error involved a considerable change in flight path to give a satisfactory landing.

Mr. E. T. Jones: The ground-controlled landing suggestion would involve the transmission of heading, attitude, airspeed and other information from the aircraft to the ground, in addition to the other difficulties of ground-controlled schemes, *e.g.*, the height of the aircraft when near the ground could not be measured accurately enough. While the transmission of the information from the aircraft did not in principle present much difficulty, the airborne equipment involved would be prohibitive.

Mr. W. J. Richards: Regarding the danger of prejudicing the provision of a good approach system by seeking a complete solution to the landing problem, it seemed worth while to search for a line of development which should lead to the latter. If the work were properly directed and sufficient effort made available, the introduction of the system for approach use should not be appreciably delayed. It should be appreciated that any system introduced would tend to remain for a considerable time, and if a system fundamentally unsuited to landing was adopted the provision of a complete solution would be put off for many years.

Mr. Bowen: The remarks on the need for thorough investigation of all the factors which went to building up the complete blind landing problem indicated the considerable amount of work required before useful results could appear. Fortunately, much had now been done or was well on the way to completion; in the process staff were becoming familiar with the problems, and already some new conceptions and ideas for applying the advances in technique of the past few years were being evolved.

Mr. Rowe: The suggestion that the aircraft designer should keep in touch with blind landing development work and see if he could help was welcomed; some points were mentioned in the lecture, but assistance in more major respects seemed possible. For example, wide runways would become practicable if short landing runs, such as seemed possible with reversible pitch propellers, were universally used; this would ease the blind landing problem considerably.

The American television-radar scheme was clearly more applicable to U.S.A. internal airlines than to many of the services operated from this country, its primary application being to control between airports. As regards blind approach, it was essentially the ground-controlled scheme with a television instead of an aural transmission.

Regarding the suggestion that a reflector might be used with a radio altimeter so as to avoid ground contour effects, unfortunately the earth was itself too good a reflector for such a scheme to be practicable.

Capt. J. Dolezal: Attempts were being made to provide a realistic presentation broadly on the lines suggested, but it was hazardous to guess the extent to which the pilot's task would be relieved; even at night, the pilot collected visually information on heading and attitude which could not easily

be included in a presentation which must be instinctively interpretable. Also, the limitations of cockpit size would force the presentation to a miniature form and in many cases to an inconvenient position.

It was agreed that a measurement of range from a ground station should assist the pilot while orbitting prior to the approach, and equipment for this was being developed.

Mr. Clough: The SCS 51 curves in Fig. 8 were obtained from an aircraft flying backwards and forwards at right angles to the runway. Simultaneous photographs were taken at three second intervals of the ground vertically beneath the aircraft, in order to fix its position, and of a milliammeter measuring the SCS 51 output. Inside three miles from the transmitter, surveyed ground markers were used in fixing the aircraft's position; outside that range, the photographs were compared with a 6 in./mile Ordnance Survey map. In all cases, errors due to camera tilt were corrected from photographed readings of a transmitting vertical gyroscope. Check flights flying across the beam in both directions were made at some ranges from the transmitter, and gave good agreement.

In addition to the results given in Fig. 8, confirmation of the order of accuracy given by the beam system had been obtained during the automatic approach work. The aircraft's track shown in Fig. 17 was obtained using the photographic method outlined above to fix its position, and a photographic record of the SCS 51 output was also obtained; the results were therefore independent of aircraft and pilot response effects, and in this case the aircraft was coming down the glide path and facing the runway as in the practical use of the SCS 51 system. The results of about 100 approaches confirmed that errors up to 30 yards occurred when the aircraft was close to the runway centre line and within a mile of the touchdown point.

No large effects due to banking the aircraft had been noticed, but quantitative measurements had not been made.

Mr. R. Ashton: The points raised relating to navigation to the vicinity of the airfield and to the orbit were not discussed in the lecture because they were outside its scope. The parking problem was much easier technically than the other difficulties involved in blind landing, and work on it could well await further progress with the latter. The other problems listed were being worked on with the general aim given by Mr. Ashton—that of developing a system which would operate safely in zero visibility and give a high landing rate.

The problem of landing blind on the sea should be much easier than the airfield problem as regards reflection troubles and other difficulties arising from irregularities in the earth's surface, but the demand for a system for land-based aircraft was such that a solution applicable to them was the major requirement.

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THE SEPARATION OF PRINCIPAL STRESSES IN PHOTO-ELASTIC ANALYSIS

by

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SUMMARY.

FOURTEEN analytical, graphical and experimental methods for the separation of the principal stresses from the photo-elastic stress pattern are discussed and a number of them described in detail. Their usefulness from the point of view of the practical stress analyst is considered.

INTRODUCTION.

The photo-elastic method can be used for either of two main purposes:

(*a*) As a qualitative design tool to obtain indications of possibly unsuspected sources of stress concentration.

(*b*) As a means of obtaining a complete analysis of a two-dimensional stress problem, *i.e.*, the determination of the separate magnitudes of the principal stresses at any point, as well as the direction of the principal planes relative to some axis of reference.

All that is required for (*a*) is the stress pattern which becomes visible and can be photographed when a loaded model cut from a sheet of suitable material is placed in a field of circularly polarised light.

Both the fundamental principles underlying this method and the modern technique of obtaining stress patterns by using monochromatic light are well known and descriptions of the necessary apparatus will be found in Coker and Filon's, Frocht's and Filon's books (Refs. 1, 2, 3).

It will be recalled that the black fringes which become apparent are the loci of points of equal principal stress difference. And since the maximum shear stress at a point is equal to half the principal stress difference these lines are also lines of equal maximum shear stress.

Apart from the qualitative picture which is often all that is required, two other pieces of information can be derived directly from the stress pattern.

Firstly, if the material of which the prototype of the model is to be made is likely to fail in accordance with the maximum shear stress theory a criterion of failure can be obtained directly, once the numerical value of the shear stress per fringe has been determined by calibration.

Secondly, if the state of stress at a point on an unloaded boundary is considered, it will be appreciated that the directions of the principal stresses at such a point must be parallel and normal to the boundary, and that the principal stress in the latter direction must be zero. From this it follows that the principal stress in the former direction can be determined directly from the stress pattern, since the difference between the principal stresses is known everywhere, and one of the stresses is zero.

If, however, the values of the separate principal stresses are required at interior points, or a complete analysis is to be performed, some other measurements or calculations must be made.

It is obvious that if the value of S, the sum of the principal stresses, can be determined at the relevant points by some analytical, graphical or experimental method, the problem will be solved completely, as the difference of the principal stresses is already known.

A large number of methods has been suggested. As the textbooks on this subject give only a few of these methods, and as some of them have only been published abroad it was felt that a summary and critical review of the available methods for the separation of the principal stresses might be useful to workers in this field.

These methods can be conveniently subdivided as follows:

i. Those based on a solution of Laplace's equation.

ii. Those based on auxiliary photo-elastic data.

iii. Those based on the measurement of other physical factors which are proportional to S.

SECTION I.

It is shown in textbooks on the theory of elasticity that Laplace's equation holds for the sum of the principal stresses in a two-dimensional system, *i.e.*, that subject to the appropriate boundary conditions

$$\frac{\partial^2 S}{\partial x^2}+\frac{\partial^2 S}{\partial y^2}=0 \qquad (1)$$

To solve Laplace's equation the boundary values of S must be known. It was pointed out above that at an unloaded boundary one of the principal stresses is zero; it follows that at such a boundary the numerical value of S equals the numerical value of the difference of the principal stresses as determined from the stress pattern. The required boundary values of S are therefore available for the solution of the Laplacian.

Three main methods are available for the solution of this equation:

(a) Mathematical analysis.

(b) Solution by successive approximations based on the expression of the Laplacian in terms of finite differences.

(c) Solution by mechanical or electrical analogy.

Method (a), except in a very few problems with simple geometrical boundaries, is impossible, and can, for all practical purposes be ignored.

Method (b) is extremely useful for calculations of this type and will now be considered in detail.

SOLUTION BY SUCCESSIVE APPROXIMATIONS.

When Laplace's equation is written in terms of finite differences, the so-called Laplace difference equation is obtained, which requires that the value of S at any point in a square net should be the average of the values of S at four adjacent points in the net.

In Fig. 1 let A, B, C, D, E, F, G, H be boundary points on a square net for which the values of S are known from the stress pattern. If the values of S at the four

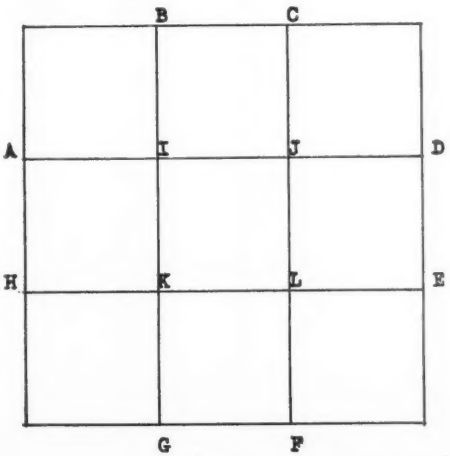

Fig. 1.

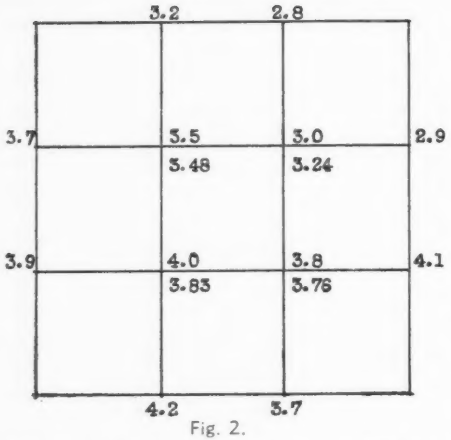

Fig. 2.

interior points are now required, the Laplace difference equation gives us four linear equations:

$$S_i = (S_a + S_b + S_j + S_k)/4 \qquad (2)$$

$$S_j = (S_i + S_c + S_d + S_l)/4 \qquad (3)$$

$$S_l = (S_k + S_j + S_e + S_f)/4 \qquad (4)$$

$$S_k = (S_h + S_i + S_l + S_g)/4 \qquad (5)$$

These equations could in this very simple case be solved as four simultaneous equations and the values of S_i, S_j, S_k, S_l so obtained.

It is, however, obvious that most problems would lead to an excessively large number of simultaneous equations which could not be solved by ordinary algebraic methods without great effort and considerable loss of accuracy. The Liebmann method of iteration is therefore used. This consists of a simple method of successive approximations.

Arbitrary values are assumed for the four unknowns and written on the network as shown in Fig. 2. The arbitrary value of S_i can then be improved by using equation (2). The improved value of S_i will be used in equation (3) to obtained the improved value of S_j and so on as shown in the figure where the improved values are written under the arbitrarily assumed values in the net. The improved values can be further improved by repeating the procedure.

The rapidity of the convergence of these values and their relation to the fineness of the net with which the area to be investigated is covered, are discussed in a paper by

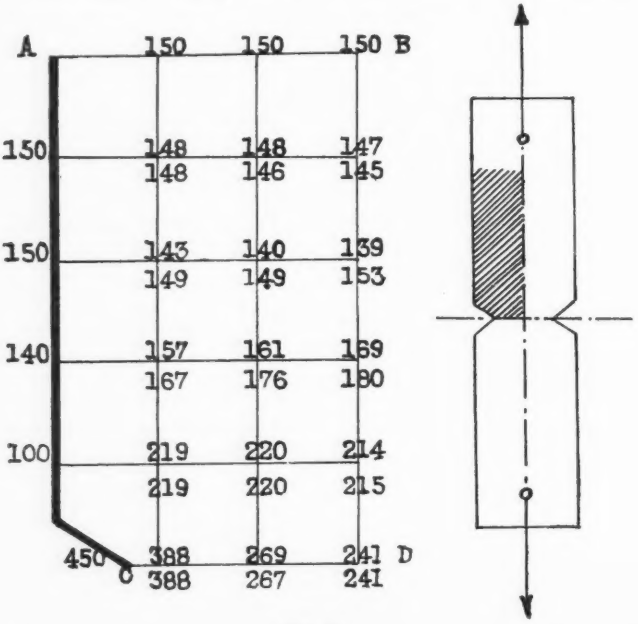

Fig. 3.

Shortley and Weller (ref. 4), who first drew attention to the usefulness of this procedure in photo-elastic analysis. Near the boundaries points will sometimes be encountered which are not equidistant from the point under consideration. In such cases the values of S must be weighted by using the following equation (see Fig. 5):

$$S_e = xy\left[S_b/(a+y) + S_a/(a+x) + S_d/(y+y^2) + S_c/(x+x^2)\right]/(x+y) \qquad (6)$$

The procedure may, therefore, be sum-

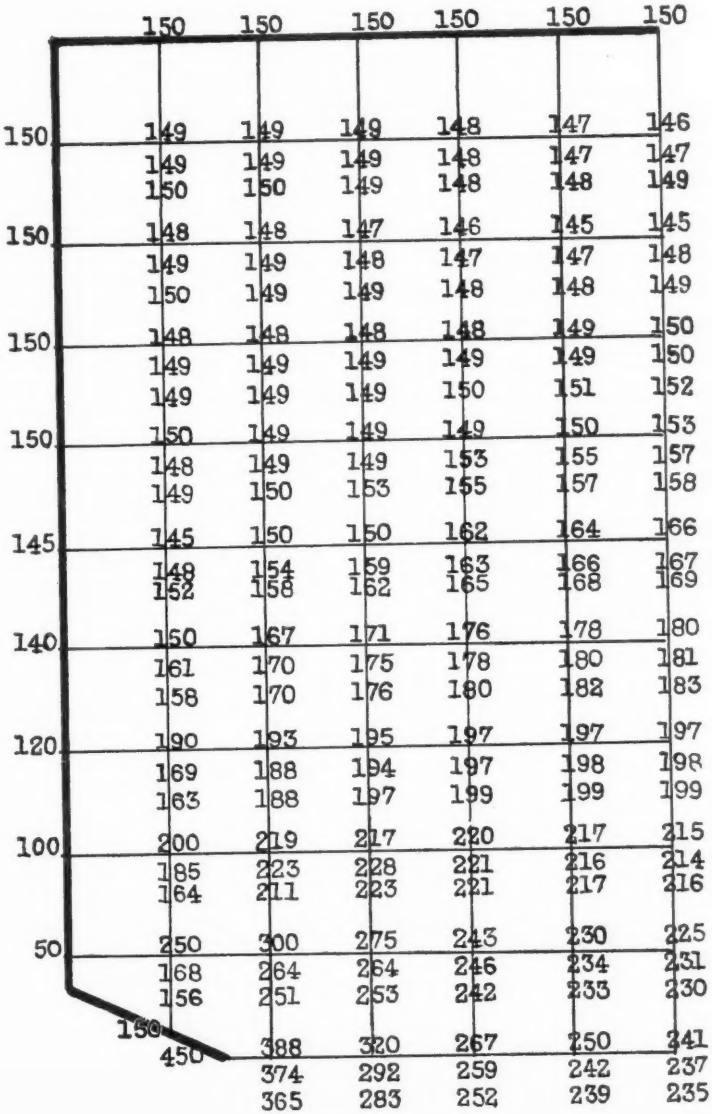

Fig. 4.

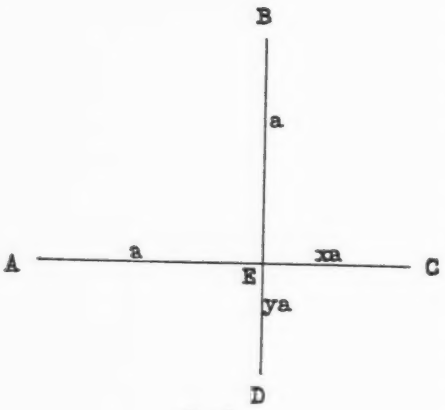

Fig. 5.

marised as follows (Figs. 3 and 4 illustrate part of the solution of an actual problem):

(1) On a scale drawing of the model draw a coarse net;
(2) Enter the boundary values of S on the net;
(3) Enter estimated values of S at all interior points on the net;
(4) Improve these values by the method outlined above;
(5) Transfer these values to a finer net;
(6) Enter estimated values of S at remaining interior points;
(7) Improve values to any desired degree of accuracy.

It will be noted that although this method is based on the mathematical theory of elasticity the complete solution requires no mathematical process more difficult than taking the average of four numerical values of S.

SOLUTION BY ANALOGY.

The most convenient method of solving the Laplacian by analogy is probably the elastic membrane method.

It is shown in textbooks on the theory of elasticity that the ordinates of a uniformly stretched membrane are given by the equation

$$\frac{\partial^2 z}{\partial x^2}+\frac{\partial^2 z}{\partial y^2}=0 \qquad (7)$$

where z is the vertical ordinate of any point above the horizontal xy plane, provided the deflections are small enough for the tangent of the slope at a point to equal the sine of the slope.

It will be noticed that equation (7) is analogous to equation (1) with z taking the place of S. It follows that a system analogous to that for the determination of S can be created by cutting a template the boundary of which is geometrically similar to the photo-elastic model. If, furthermore, the z ordinates erected from this boundary are at every point made to represent the boundary values of S to some scale, completely analogous conditions will have been established.

An evenly-stretched rubber membrane can be attached all round and the height above the xy plane of all points where S is required can be measured by means of an ordinary depth gauge.

It may sometimes be useful to make measurements on a rubber membrane with large deflections; the admittedly approximate result obtained in this way can then be improved by the numerical method.

Soap films have been used in this connection in place of rubber membranes; they have the advantage that soap films are automatically uniformly stretched, but the disadvantage that it is difficult to maintain a soap film for any appreciable time unless the model is very small.

Very abrupt changes in the boundary values of S cause difficulties in the use of this method whether a soap-film or a rubber membrane is used. Soap films tend to break at points on the boundary where the ordinates change very rapidly, and a rubber membrane will not maintain a uniform tension in the vicinity of such a point (Ref. 5, 13, 20, 22).

Other solutions of Laplace's equation by analogy that have been suggested are a mechanical analyser by Grosser (Ref. 6) and electrical potential analysers described by Paschkis and others.

The mechanical analyser is based on the fact that Laplace's equation holds for the deflections of what may be termed a shear membrane, *i.e.*, not a uniform tension membrane as used above, but a theoretical membrane which deflects due to a shearing action at right angles to the plane of the membrane. It can be shown that the deflections of such a membrane fit the Laplace equation without the limitation of magnitude of the deflections which holds for the uniform tension membrane. A mechanical model of a "shear membrane" consists of a number of spring-loaded rods which are all parallel to each other and at right angles to a reference plane. Each rod can then be considered to be a point on an imaginary shear membrane. Satisfactory results are claimed for this form of analyser.

A much more widely used method is the electrical analogy of Laplace's equation. This analogy can be based either on a set of networks the potential differences in which fit Laplace's equation, or by setting up circuits in which the potential differences satisfy Laplace's difference equation, *i.e.*, that the value of the function measured is equal to the average value of the function at four adjacent points in a square net. Electrical analogies of this kind have been described and suggested by Hogan, Paschkis, Redshaw and others (Ref. 7, 8, 23).

Electrical analysers of this type can be used to solve even more general problems than Laplace's equation, such as the solution of Poisson's equation; the expense of setting up the electrical apparatus would appear to rule out this method of solution in most cases where some such device is not necessary to solve other types of problems, such as those of heat flow, etc.

A method which seems preferable to the setting up of fairly complicated networks, but which is based on the same principle, is to build up a replica of the boundary of the model and apply voltages to points on the model which are proportional to the corresponding boundary values of S, as determined from the isochromatics. If the whole is then immersed in a tank containing an electrolytic solution, the voltage at an interior point would satisfy Laplace's equation, and would by analogy be proportional to the corresponding value of S (Ref. 21).

SECTION II.

A number of methods for the separation of the principal stresses based on the use of isoclinics are available. Probably the most important of these are due to Filon, Frocht and Neuber (Ref. 1, 2, 3, 9, 15).

One other method will be considered in this section. This is the method of oblique incidence first suggested by Drucker in 1943 (Ref. 17). All these methods have one advantage in common. No additional apparatus is required; any laboratory equipped to obtain the ordinary isochromatic stress patterns can determine isoclinics (the curves connecting all points at which the principal planes have the same inclination to some reference line), or the additional stress pattern required for the method of oblique incidence.

The isoclinics appear in addition to the ordinary stress pattern when the loaded model is viewed in a plane polariscope, which differs from the circular polariscope in having no quarter wave plates.

Points in the model where one of the principal planes is parallel to the principal plane of the polariser do not affect the passage of polarised light, and it follows that such points will appear black when viewed through the crossed analyser of a standard plane polariscope.

Rotation of the analyser and polariser through 5, 10, 15, . . . degrees will therefore give the isoclinics of these parameters as black fringes in addition to the ordinary stress pattern. Since both the isoclinics and the isochromatics appear at the same time it is usual to use white light in preference to monochromatic for the determination of the isoclinics, as in white light the isochro-

matics change colour with the increase of load while the isoclinics remain black.

THE USE OF ISOCLINICS.

It is one of the drawbacks of using any of the methods based on data derived from the isoclinics that these curves are not always very clearly defined, and they must therefore be corrected and smoothed out before they can be used as the basis of further calculations. This is done from considerations of symmetry and by bearing in mind that, for instance, the 5° isoclinic must intersect a point at an unloaded boundary where the normal to the boundary makes an angle of 5° with the reference line. Isoclinics have often to be extrapolated to points on the boundary as they are easily obscured by the existence of small machining stresses.

When the isoclinics have been corrected, the next step is usually to draw the stress trajectories (curves having principal planes tangent and normal at every point). With some experience stress trajectories can be drawn reasonably accurately by inspection on a diagram showing the isoclinics. Constructions for obtaining these curves rather more accurately, if much more laboriously, are given in Frocht and Filon (Ref. 2, 3).

Filon's method of graphical integration and Frocht's shear difference method are based on the same differential equations for the equilibrium of an element in a two-dimensional system of stress, but while the former method gives the separate principal stresses along a stress trajectory, the latter gives the principal stresses on an arbitrary straight line.

The equations of equilibrium for a small element bounded by stress trajectories can be shown to reduce to:

$$\frac{\partial p}{\partial S_1}+\frac{p-q}{\rho_2}=0 \qquad (8)$$

$$\frac{\partial q}{\partial S_2}+\frac{p-q}{\rho_1}=0 \qquad (9)$$

where p and q are the principal stresses, ∂S_1 and ∂S_2 are elements of length along two stress trajectories, and ρ_1 and ρ_2 are the respective radii of curvature of the stress trajectories.

On integrating equations (8) and (9) between the limits a and b we get

$$p_a=p_b-\int_b^a \frac{p-q}{\rho_2}dS_1 \qquad (10)$$

$$q_a=q_b-\int_b^a \frac{p-q}{\rho_1}dS_2 \qquad (11)$$

Clearly the radius of curvature of a stress trajectory is very difficult to measure. For this reason Filon suggests the following transformation (see Fig. 6); $I(\theta)$ and $I(\theta+\delta\theta)$ are two adjacent isoclinics; S_1 and S_2 are two stress trajectories.

In the limiting case when $\delta\theta\to 0$ angle $OXY=\pi-\beta$. Therefore $OX/OY=-\cot\beta$ and $OY=\rho_2 d\theta$.

Denoting OX by dS_1 we get

$$dS_1/\rho_2=-\cot\beta\,.\,d\theta$$

Similarly $dS_2/\rho_1=\cot\beta^1\,.\,d\theta$.

Therefore equations (10) and (11) become:

$$p_a=p_b+\int_b^a (p-q)\cot\beta d\theta \qquad (12)$$

$$q_a=q_b-\int_b^a (p-q)\cot\beta^1 d\theta \qquad (13)$$

It is obvious that the integrals in equations (12) and (13) cannot in general be solved analytically, but must be integrated graphically. The procedure for this method of solution therefore consists of the following steps:

(1) Plot and correct the isoclinics.

(2) Plot the stress trajectories.

(3) Determine the quantities required for substitution in equations (12) and (13).

(4) Plot $(p-q)\cot\beta$ against θ and evaluate the integral in equation (12) between any desired limits. This integration will be begun from a point on a free boundary.

(5) Plot $(p-q)\cot\beta^1$ against θ and proceed as in step (4) above.

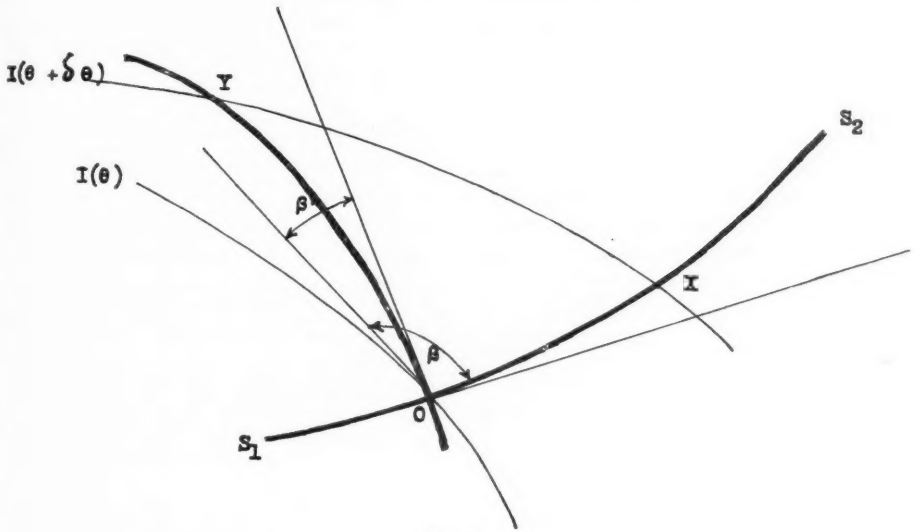

Fig. 6.

Frocht's shear difference method can be used for the solution of the same type of problem as Filon's method (Ref. 3).

Frocht's "rapid" method for the determination of the principal stresses across a section of symmetry is also based on the equations of equilibrium and makes use of Mesnager's theorem which states that the principal stresses tangent to a given stress trajectory are a maximum or minimum where an isoclinic cuts the stress trajectory at right angles. Such points are called cupic points (Ref. 3 and 15).

The procedure is:

(1) Determine the cupic points.
(2) Plot the $(p-q)$ curve as obtained from the stress pattern.
(3) Determine the slopes of the p and q curves wherever possible, by considering equations (8) and (9).
(4) Investigate the manner in which the slopes of the two curves vary, again by considering the equilibrium equations.
(5) Draw approximate p and q curves.
(6) Correct the curves by making the area under the curve of the stress normal to the axis of symmetry equal to the applied load in that direction, *i.e.*, by considering the external equilibrium of one half of the model.

Neuber's method (Ref. 9) is based on the use of the elastic equations in place of the equations of equilibrium used by Frocht and Filon. He derives equations which enable him to obtain the isopachic lines, *i.e.*, the lines of constant S, by means of a graphical construction. The method is claimed to be shorter than Filon's or Frocht's, but the difference in the time required to solve a particular problem does not appear to be very appreciable.

Drucker's Method.

The method of oblique incidence, although also based on additional photo-elastic data, differs from the methods discussed above in that it requires no graphical constructions.

All that is required in the use of this method is the determination of the fringe order at the point under consideration, the plane of the model being in an oblique position relative to the direction of the incident ray of circularly polarised light, in addition to the usual determination of the fringe order

when the plane of the model is at right angles to the direction of the incident ray.

The theory on which this method is based is as follows:

It is assumed that the model is free from initial double refraction and initial stress. Let the retardation in fringes observed at a particular point be n, when observed at normal incidence. Then from the experimental stress-optic law on which the photoelastic method is based

$$n=(p-q)t/C \qquad (14)$$

where p is the numerically larger principal stress, q the numerically smaller principal stress, t the thickness of the model and C the stress-optical coefficient of the model material. If the model is now rotated about p through an angle θ, the secondary principal stresses in the plane perpendicular to the incident ray will be p and $q\cos^2\theta$. The light now travels through a thickness $t\cos\theta$ and therefore the relative retardations at oblique incidence is

$$n'=(p-q\cos^2\theta)t/(C\cos\theta) \qquad (15)$$

If we write $a=pt/C$ and $b=qt/C$ equations (14) and (15) become

$$n=a-b \qquad (14a)$$

$$n'=(a-b\cos^2\theta)/\cos\theta \qquad (15a)$$

Solving equations (14a) and (15a) we get

$$a=\cos\theta\,(n'-n\cos\theta)/\sin^2\theta \qquad (16)$$

$$b=(n'\cos\theta-n)/\sin^2\theta \qquad (17)$$

In these equations, n, n' and θ are known and therefore a and b can be calculated at any point. If t/C is known the separate values of the principal stresses are known.

It must be borne in mind that the retardation for oblique incidence, n', is due to the average stress over a length $t.\tan\theta$ and not due to the stress at the mid-point of this length. It follows, therefore, that it is advisable to make t as small as possible, in fact, as small as is consistent with obtaining a good fringe photograph under the particular loading conditions. Difficulties in connection with this approximation fortunately do not occur frequently at interior points where separation of the principal stresses is usually required.

SECTION III.

Two methods will be mentioned under this heading: the measurement by various means of the lateral deformations of the model, and the measurement of thermal changes due to stress.

Of these the second is interesting but not very useful in practice.

It depends on an equation arrived at by thermodynamic reasoning (Ref. 2), that a sudden application of stress under adiabatic conditions causes a rise of temperature given by

$$dT=-\alpha T(p+q)/csJ \qquad (18)$$

where α is the coefficient of linear expansion per degree Centigrade, T is the absolute temperature, c the specific heat of the material, s the specific gravity of the material, and J the mechanical equivalent of heat.

The conditions are reasonably near adiabatic for a bad conductor of heat; but as the change of temperature is of the order of a quarter of a degree Centigrade for a value of S of 5,000 lb./sq. in. in a celluloid model, the method is of interest to the physicist rather than the practical stress analyst.

Coker carried out measurements of this kind by means of a thermo-couple, but very considerable precautions and quite expensive apparatus appear to be needed.

The measurement of lateral extensions, *i.e.*, the deformations in a direction at right angles to the plane of the model, is based on the well-known equation in the theory of elasticity which gives the deformation δ at a point of a sheet subject to a two-dimensional stress system

$$\delta=-(p+q)t/mE \qquad (19)$$

where t is the thickness of the sheet, $1/m$ is Poisson's ratio of the model material and E is Young's modulus for the model material.

The displacements involved are extremely

small, and an extensometer reading to one-millionth of an inch is necessary.

Coker designed such an instrument (Ref. 1, 2) and used it very successfully for a number of years. In fact, all the pioneer experiments in photo-elasticity were carried out with the aid of this extensometer. The use of Coker's extensometer, which is described and illustrated in Refs. 1 and 2 requires considerable care and skill which is indicated by the fact that very few other workers in this field have used this method of determining S.

An interferometer strain gauge was suggested by Mesnager in 1901 and has been used by Vose (Ref. 16) for the measurement of this lateral deformation. The interferometer strain gauge essentially consists of two optical flats the relative displacements of which are proportional to the lateral deformation at the point under investigation. The small variations in distance are measured by counting the number of interference fringes which become visible during the loading and unloading of the model. Monochromatic light is used for the observation of the fringes.

Both the measurement of the lateral deformation by the Coker extensometer and by the interferometer strain gauge are essentially point-by-point methods which require loading and unloading for every observation, not by any means a simple matter if the system of loads is at all complicated.

Frocht (Ref. 11) has obtained photographs of the isopachic lines by an interferometer method which had been suggested by Tesar (Ref. 24). He placed a polished model close to an optical flat so that the planes of the model and the flat were parallel. On application of the load the lateral deformations of the model caused variations of the width of the layer of air between the model and the flat which gave rise to interference fringes, which are in fact the isopachic lines, the lines of constant S, which are required for the complete solution of a two-dimensional stress problem.

CONCLUSIONS.

One limitation which all the methods discussed in Section I have in common is the fact that difficulties arise on those parts of the boundary of a model which are loaded. An artificial boundary can, however, often be created on which no outside loads act and along which the stresses are known. The problem illustrated in Figs. 3 and 4 is an example of this. The transverse boundaries AB and CD were chosen at points where the stress pattern indicated a field of uniform tension; in fact, these boundaries are sufficiently far away from the sources of stress concentration and the points of application of the load to be unaffected by them (St. Venant's principle).

The advantages of the method of successive approximation are its inherent simplicity and the fact that no additional apparatus is required. The labour involved in the solution of a complicated problem is considerable, even when a calculating machine is used. There are a number of ways of somewhat shortening the arithmetic, some of which are indicated by Shortley and Weller (Ref. 4), Frocht and Leven (Ref. 10) and Emmons (Ref. 25).

The main drawback of the membrane analogy is the necessity of making a different model for the solution of each problem. The electrolytic analogy described in this section suffers from the same disadvantage, which is not shared by the network methods; the same set of networks is used for all the problems. The initial cost and labour involved in building the latter type of analyser are, however, quite considerable. As the same network, in fact a square net, is used for the solution of all problems it follows that curvilinear boundaries can only be approxition if the model boundaries are reproduced mated; this can be quite a good approximato a large scale.

All the graphical methods described in Section II require a sound grasp of the fundamental properties of isoclinics and stress trajectories, and the solution of problems by any of these methods could not be delegated to a computor in the same way as the numerical solution of Laplace's equation could be.

With experience in the use of Frocht's "Rapid" method it will be found that it deserves its name by comparison with the other graphical methods when values of the principal stresses are required only on axes of symmetry.

With the same limitation the method of oblique incidence will also be found very useful. With a complex load system this method leads to obvious experimental difficulties. When the separate principal stresses are required only at certain specified points, this method provides a useful point-by-point approach.

The methods of solution discussed in Section III being essentially point-by-point methods involve no difficulties in connection with loaded boundaries, when no convenient artificial boundary can be created. A complete solution by any lateral extensometer method is bound to be very laborious.

Frocht's isopachic line method is attractive, as it involves no apparatus which is not available in the ordinary photo-elastic laboratory, apart from an optical flat for use as a reference plane. Large optical flats are, however, very expensive, and the method clearly calls for very accurate alignment, and a very well-polished specimen.

In comparing the usefulness of the methods described in the different sections of this paper, it will be seen that the numerical solution of Laplace's difference equation is probably the most generally useful; that for partial solutions the methods of Section II have much to be said for them while the methods of Section III may have to be resorted to in problems involving complicated loaded boundaries.

The separate determination of the principal stresses by pure interference methods, *i.e.*, the determination of the absolute retardation at a point instead of the relative retardation (Ref. 18, 19) has not been discussed in this paper as these methods are not based on the photo-elastic stress pattern.

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A REVIEW OF RECENT PROGRESS IN AIRCRAFT GUN DESIGN AS IT AFFECTS INSTALLATION IN AIRCRAFT

by

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INTRODUCTION

EXPERIENCE with the installation of guns in aircraft in recent years suggests that there has been little co-operation between gun designers and aircraft designers. This becomes more apparent as gun calibres increase and if satisfactory fighting aircraft are to be produced in the future, closer co-operation between gun designers and aircraft designers will be necessary. In consequence, a brief review of the progress of gun design in recent years, with special reference to its effect on installation, may be of interest.

From 1918 to 1938 the standard guns used in the Royal Air Force were the Lewis gun and Vickers Maxim gun, both Army guns modified for air cooling. The installation of these guns had reached a standard form by 1918 which was adhered to for the best part of 20 years. The Lewis gun was mounted on a Scarff ring and used for bomber defence and the Vickers guns were mounted in pairs in the cockpit of fighters and synchronised by the Constantinesco gear to fire through the airscrew disc. This arrangement was rarely departed from and aircraft designers gave the matter little thought.

EARLY TYPES

By early 1938 two new guns were being issued to the Service in small but ever increasing quantities. First, the Vickers G.O. gun was issued as a replacement for the Lewis gun; like the Lewis gun it was a gas-operated, magazine-fed gun of .303" calibre and was designed specifically for use with the Scarff ring. The advantages of this new gun were its greatly improved performance and reliability; its rate of fire was nearly twice that of the Lewis.

Its reliability, both as regards functional stoppages and breakage of components, was greatly superior to the Lewis. With the Lewis gun it was necessary to carry spare parts and special tools for clearing stoppages, and although similar provision was originally made for the Vickers G.O. gun, experience during early trials showed that this was quite unnecessary and subsequently no spares were carried in the air. Also, as it was so similar to the Lewis gun, it gave rise to no unusual installation problems. Unfortunately, although the Vickers G.O. gun had been designed specially for aircraft use, it had

been designed for a type of aircraft which by 1938 had become obsolete.

For bomber defence the free gun mounted on a Scarff ring, or its equivalent, was replaced by the power-operated multi-gun turret. The Vickers G.O. gun was unsuitable for turret installations because it was magazine-fed and a gunner could not work his turret and replace magazines on four guns at the same time. In consequence, the Vickers G.O. gun was virtually obsolete at the time of its introduction and had largely disappeared from operational use by 1942.

The Browning gun was introduced into the Service about the same time as the Vickers G.O. gun. It was an American gun designed by the Colt Automatic Arms Co. but was considerably modified by the Air Ministry Technical Staff to make it suitable for Air Force use.

Like the Vickers Maxim gun which it replaced, the Browning was an air-cooled, recoil-operated, belt-fed gun of .303" calibre, using a disintegrating metal belt. As finally developed for the Royal Air Force the Browning was the most successful gun of its size in use by any Air Force. Its performance was a considerable improvement over the Vickers Maxim gun and its reliability was far superior. As in the case of the Vickers G.O. gun, it was found quite early that spare parts and special gear for clearing stoppages were not necessary. Once the Air Force armourers had become skilled in its maintenance the gun was at least as reliable as an engine.

During the operations in Western Europe in 1944-45 the 2nd Tactical Air Force reported an average stoppage rate of one stoppage per 15,000 rounds fired.

As the Browning gun was modified to be easily interchangeable with the Vickers Maxim, when used in the standard twin-gun fuselage type of installation, it gave rise to no installation problems. When it was decided to use eight gun batteries, however, the question arose as to how best to fire eight guns simultaneously. In twin-gun fuselage installations the guns were fired hydraulically by the C.C. Gear, and the single forward-firing guns of twin-engined bombers were usually fired by a cable-operated C.C. trigger motor.

It was obvious from the start that the pilot would not be able to fire eight guns simultaneously by cable. This left three alternative methods; pneumatic, hydraulic and electric. For various reasons, mainly the fact that pneumatic services were already provided for the brakes on every aircraft, pneumatic firing was adopted as standard for fixed gun fighters. This complicated the gun installation, as it was now necessary to provide, in addition to the guns, a somewhat elaborate pneumatic system of pipe lines, reducing valves, pressure gauges, air bottles, engines compressors, and so on.

With the introduction of multi-gun turrets for bomber defence the Browning became the standard turret gun. The reason for this was that its reliability, combined with the fact that it was belt-fed, meant that the gunner could work his turret without having to give any attention to the guns. Its use in turrets meant a reconsideration of the question of firing; pneumatic firing was not so convenient for turrets as it was for the fixed-gun fighter and hydraulic and electric-firing gears were developed for use with hydraulically - and electrically - operated turrets respectively.

The use of the Browning gun in turrets raised another installation problem. In a turret the guns move relatively to the ammunition tanks, sometimes in elevation only, but sometimes in elevation and traverse. This invariably means that the belt must be twisted some time during its path from the ammunition box to the gun. The tighter the belt can be twisted the more compactly the belt runs; in consequence turret designers usually give the belt as much twist as it will take without breaking or giving rise to gun stoppages.

As the tendency of the turret designers was to over-estimate the flexibility of the

belt, frequent stoppages arose in some of the early turret designs due to jamming and breakage of the belt. This was aggravated by the fact that belt links were manufactured by the million by a large number of manufacturers and it proved extremely difficult to obtain a consistent quality of belt.

Trouble was also experienced with the strength of the belt, which will only withstand a certain pull before it either breaks or distorts sufficiently to cause a stoppage in the gun. This limits the length of belt that can be used. In an effort to improve both strength and flexibility, modifications were made to the design of the link, but these often affected adversely the functioning of the link in the gun. As far as turret installations were concerned the belt remained the most unsatisfactory feature of the Browning gun.

As soon as the Browning was used under operational conditions trouble was experienced because of guns freezing up. Like most high performance mechanisms, a machine-gun works better if it is properly lubricated, and in the early days armourers were in the habit of applying oil in liberal quantities. It was found, however, that the oil congealed at low temperatures and would completely stop the gun.

This was overcome by oiling the gun lightly with a mixture of paraffin and anti-freeze oil, but its lubricating properties were low and it was useless as a rust preventor. However, under dry, cold conditions this prevented stoppages due to congealed oil at the expense of increasing the difficulties of maintenance.

It was now found that if a machine first passed through moist air which condensed on the guns and subsequently entered air below freezing point the condensate froze on the guns and caused stoppages. On fixed-gun fighters this was tackled in two ways. First, the gun bays were sealed and heated, usually by means of hot air from the exhaust system; secondly to prevent cold moist air blowing down the barrel into the gun bay, the barrel had to be sealed.

Where the guns were sunk into the wing, this was done by doping a fabric patch over the blast tube, but where the gun projected beyond the wing a rubber cover was placed over the gun muzzle. The disadvantage of this scheme was that it would only guarantee that the guns would remain unfrozen for the first burst; after that the cold air could enter *via* the barrel.

On bomber aircraft the problem was more difficult. The turret could not be effectively sealed and heated in the earlier designs; the use of electric heaters was proposed, but it was never possible to take sufficient current off the aircraft electrical system for electric heating to be really effective. Some improvement was effected by using the rubber muzzle covers developed for fixed-gun fighters.

These three problems, firing, belt strength and flexibility, and gun heating were the main troubles experienced with the Browning gun, from the design aspect, and all called for co-operation with the aircraft designer for their successful solution.

THE GERMAN M.G.17

The German equivalent to the .303 Browning Gun was the M.G.17. This was a recoil-operated belt-fed gun of rifle calibre (7.92 mm.) designed and manfactured by the Mauser Co. As regards performance, weight and overall dimensions there would appear to be little to choose between the Browning and the M.G.17.

The weak point of the M.G.17 was the type of belt used. This was a metal belt of the non-disintegrating type, and whereas the empty belt was ejected from the Browning as a number of separate links which could be jettisoned immediately or easily collected in a box, in the M.G.17 the empty belt left the gun in a continuous length. It could not be jettisoned and was not easily collected in a box and some fairly elaborate arrangement had to be devised to keep it clear of

the gun. This not only made the installation of the gun more difficult, but increased the tendency to stoppages. This belt was also less flexible than that of the Browning and it would have been very difficult to install the M.G.17 in a four-gun turret.

Mainly as a result of the belt used, the M.G.17 was certainly less reliable than the Browning and more difficult to install.

THE 20 mm. HISPANO CANNON

It had been obvious for some years before 1939 that, with the increasing size of aircraft and engines, it would ultimately be possible to carry sufficient armour to give a large measure of protection against rifle calibre projectiles to the more vulnerable parts of an aircraft, *i.e.* tanks, engines and crew. The question of adopting larger calibre guns was considered and the final choice of the R.A.F. was for a high velocity projectile of 20 mm. calibre.

The gun adopted was one developed by the Hispano Suiza Engine Co. for use with their aero-engines. It became the standard fighter armament from the end of 1940 onwards but its installation gave aircraft designers some considerable headaches. This gun was adopted by the Air Ministry because it was the most efficient 20 mm. weapon on the market at the time, both as regards weight and performance. It was some 30 per cent. lighter and 30 per cent. faster than its competitors; it was gas-operated and magazine-fed.

It suffered from two serious disadvantages, however, which were not fully realised at the time of its adoption. First, unlike the Browning, which was the result of 20 years development and was the standard weapon of the U.S. Air Service for some years before the Air Ministry adopted it, the Hispano 20 mm. gun was virtually an experimental weapon at the time of its adoption, and had not previously been subjected to service conditions. Consequently it was being developed concurrently with its production for operational use. This was further complicated by the fact that the gun was a French design and, after the summer of 1940, the Air Ministry had no contact with the original designers and all subsequent development had to be done without their help.

The result was that the Hispano was not very reliable in its early days and even after four years intensive development it never reached the high standard of the Browning gun. The average stoppage rate reported by the 2nd Tactical Air Force for the Hispano gun during the operations in Western Europe was 1,560 rounds per stoppage. Although nearly ten times the Browning gun rate, it was still low enough to make the Hispano a serviceable weapon and it is doubtful if any other weapon of this calibre gave any better results.

The other disadvantage of the Hispano gun was the fact that it was a magazine-fed gun designed specifically for use with the Hispano Suiza engine. These two facts gave rise to most of the installation troubles experienced with the Hispano gun.

The adoption of a high-velocity 20 mm. projectile would immediately give rise to two serious installation problems whatever design of gun was used, *i.e.* the increased weight and bulk and increased recoil loads. Assuming approximately the same velocity, the weight and overall dimensions will tend to increase as the square of the calibre and the recoil loads as the cube of the calibre.

This means that whereas the .303" calibre guns could easily be fitted into a structure whose design was governed primarily by strength and aerodynamic considerations, the 20 mm. gun demands modifications to the basic structure. In wing installations particularly, when 20 mm. guns are fitted, the structure is very different from what it would be if designed for strength and aerodynamic considerations alone. In the case of the Hispano gun the weight and overall dimensions work out at between 4 and 5 times those of the Browning. The recoil loads increased as some power of the calibre.

No accurate figures for the Browning were ever obtained, but a recoil load of 100 lb. was used for stressing purposes. No accurate method was available for measuring recoil loads when the Hispano gun was first adopted and recoil loads of 1,500 lb. to 2,000 lb. were used for stressing purposes. When more accurate methods had been evolved by the Royal Aircraft Establishment it was found that the recoil loads varied considerably between different aircraft and between different gun mountings and might be anything from 1,500 lb. to 5,400 lb.

As already mentioned the 20 mm. Hispano Gun was designed to be mounted between the cylinders of a Hispano Suiza aero-engine with the barrel passing through the hollow shaft of the geared airscrew. A diagrammatic arrangement of this installation is shown in Fig. 1. In order to reduce the recoil loads as much as possible, it was decided to allow the whole gun to recoil a small amount, approximately 16 mm., although to leave a margin of safety, the gun was dimensioned to allow for 30 mm. maximum recoil.

This meant that the gun had to be slidably mounted; for this purpose the front end of the gun body had two short slides which engaged in grooves cut in the engine crankcase as shown at A, Fig. 1. Halfway up the barrel a piston was fitted which slid in a cylinder which was attached to the engine crankcase. This piston formed the front bearing for the gun and the rearward movement of the gun was opposed by a recoil spring round the barrel which butted against the front face of the front bearing cylinder, as shown at B, Fig. 1. When the gun fired it recoiled backward approximately 16 mm., compressing the recoil spring; the energy stored in the spring then returned the gun to its forward position.

The piston and cylinder which formed the front bearing was also supposed to act as an air dashpot and absorb the energy of the spring during the forward motion of the gun; actually it was inefficient, and the "run-out" loads arising when the piston hit the bottom of the cylinder were much higher than the recoil loads, peaks of 8,000 lb. having been recorded.

The Hispano gun was fed by means of a circular magazine holding 60 rounds of ammunition, the ammunition lying along the axis of the gun. It is obvious that if the magazine was allowed to recoil with the gun, the ammunition would be vibrated violently backwards and forwards in the magazine. As the ammunition had a sensitive cap at one end, and in some cases an even more sensitive fuze at the other, this motion had to be prevented. In consequence, the magazine and the gun component to which it was attached had to be fixed to the engine so that it did not recoil with the gun.

The gun designers took advantage of this fact in the cartridge case ejection. Apart from reducing the recoil load, the 16 mm. recoil was also necessary to ensure correct ejection of the empty cartridge case.

All this meant that whereas, with the Browning gun, the attachment to the aircraft structure consisted of two bolts, for the His-

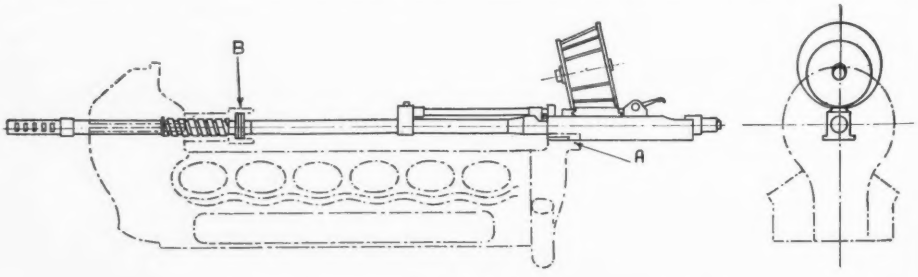


Fig. 1

pano gun the aircraft designer had to reproduce the mounting conditions of the Hispano engine and provide slide grooves for the gun body, a cylinder for the front mounting piston and an anchorage for the magazine carrier. Moreover, the rear slides and front cylinder had to be properly lined up and the whole arrangement had to have the same rigidity as the Hispano engine crankcase. This was not easy in a wing installation and the last point in particular was constantly overlooked.

The first Hispano gun installation to go into service was on the Spitfire IB, which had one gun in each wing. The first and most obvious problem was the magazine. With the gun in its normal upright position, it would have been necessary to build a huge blister on the wing to fair in the magazine, which would have extended from the leading-edge to the trailing-edge, have taken miles per hour off the speed and probably affected stability as well.

In consequence, it was decided to mount the gun on its side. This was a great improvement from the aerodynamic point of view and reduced the blister on the wing to reasonable dimensions. From the gun point of view it was bad. First, the weight of the gun at the rear, instead of being taken on the bottom of the two slides as intended, was now taken on the edge of one slide. Secondly, the gun in its normal position ejected the empty cartridge case downwards; with the gun on its side, ejection was sideways. This meant that deflectors had to be used to turn the ejection path of the case through 90°. Previous experience with sideways-ejecting guns had shown that the width of the ejection chute must be at least the length of the cartridge case, otherwise the cartridge case was liable to bounce back into the gun.

The interest of the aircraft designer was to keep the ejection hole as small as possible, for aerodynamic reasons. Thus the ejection chutes were made too small in the first instance. In addition, the aircraft structure to which the mounting was attached was not as rigid as the Hispano engine. This meant that the front and rear bearing points were liable to get out of alignment and the gun was liable to short recoil, due to flexing of the structure. As a result the early Spitfire installations were in constant trouble with mal-ejection and misfeeds. On top of this the magazine was a constant source of trouble, giving frequent misfeeds. Altogether, this installation was a perpetual headache for the ground staff.

When the Hispano Gun was first adopted the Air Ministry realised that the magazine was an undesirable feature, mainly because it restricted the amount of ammunition which a fighter could carry to 60 rounds per sortie. Concurrently with the adoption of the gun steps were taken to obtain a belt feed as an alternative to the magazine. Experience with the Spitfire IB showed the magazine to be even more objectionable than was anticipated. Not only did its size force the aircraft designer to install the gun on its side and give rise to the troubles mentioned above, but the magazine itself was unsatisfactory. As originally designed by the Hispano Suiza Co. the magazine was not suitable for mass production, and it was redesigned to suit the production methods available, but it never functioned satisfactorily under Service conditions.

By the time the Spitfire installations had got into service a satisfactory design of belt feed had been obtained, designed by the French National Arsenal at Chatellerault. It used a disintegrating metal belt, was worked by the recoil of the gun and used the same attachment to the gun as the magazine.

Although the feed remained the weakest part of the Hispano gun and a large proportion of all stoppages experienced were due to the feed, it was greatly superior to the magazine in every way. It was more reliable, it enabled more ammunition to be carried per sortie, and it was much easier to install. Fig. 2 shows the space saved by fitting the belt feed in place of the magazine. Also its use enabled wing guns to be

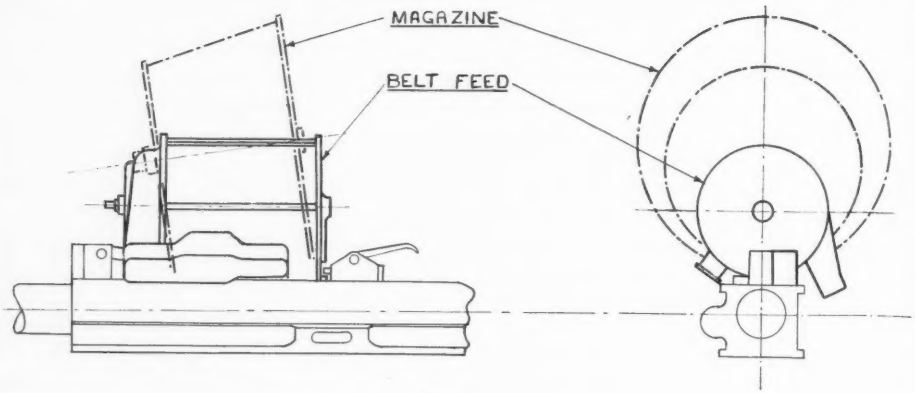


Fig. 2

mounted upright. As a result of the successful introduction of the belt feed no further magazine installations were used and the magazine became obsolete for air use.

The adoption of the belt feed, however, raised another installation problem not present with the magazine. The belt feed was driven by the recoil of the gun, the belt feed—like the magazine— remaining stationary while the gun recoiled, and this relative movement was used to wind up a driving spring in the belt feed. Hence in a belt feed installation it was essential to have full recoil of the gun every round fired, otherwise the driving spring would run down and slack feed stoppages would result. To ensure that the belt feed was fully wound at each stroke the minimum recoil was increased from 16 mm. to 20 mm., the usual figure aimed at being 20-25 mm. It was found that the operation of the belt feed absorbed a large proportion of the recoil energy of the gun and it was necessary to increase the amount of energy available.

The original gun had a recoil reducer fitted to the muzzle. This was a device for deflecting backwards the gas expelled from the barrel and so counteracting the recoil of the gun. It was found that if the recoil reducer was removed there was then sufficient energy to work the belt feed. In consequence, the recoil reducer became obsolete with the introduction of the belt feed.

Another result of using the belt feed was that a greatly increased load was thrown on the anchorage of the magazine carrier. With the magazine this was a small load due to the friction between the gun and the magazine carrier. With the belt feed it was the load due to the amount of recoil energy absorbed in working the belt feed. This amounted to some 2,000 lb.

It will be seen that if the anchorage for the magazine carrier was too flexible, although the recoil of the gun relative to the aircraft structure might be correct, the recoil of the gun relative to the magazine carrier was reduced, and might be reduced sufficiently to prevent the feed spring being wound up. This occurred on some early installations.

The next Hispano installation after the Spitfire Ib was the Hurricane IIc. This was a great improvement on the Spitfire; in the first place the belt feed was now available and the gun was mounted upright, thus avoiding the empty case ejection troubles. In addition, Hawkers adopted an entirely new method of mounting the gun. This is shown in Fig. 3. The rear slide was not used; instead the gun was secured to the bracket A, which could rotate about the shaft B. The front mounting cylinder C was in the form of a ball joint. When the gun fired the recoil was taken up by the gun swinging backwards about the shaft B.

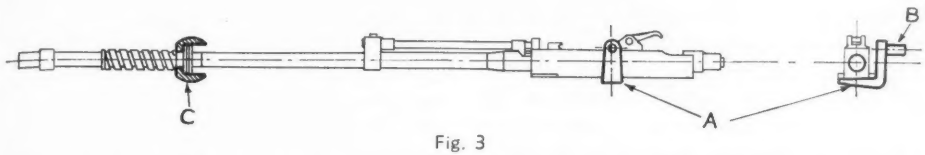


Fig. 3

The change of angle of the gun due to the rotation of the bracket was taken up by the ball joint of the front mounting cylinder. In this arrangement the friction in recoil was greatly reduced and the alignment of the front and rear bearings was less critical.

The Hurricane design was so successful that, with variations, it became the standard method of mounting the Hispano gun. From this time onwards the chief installation problems on the Hispano gun were obtaining *consistently* sufficient recoil to work the belt feed and satisfactory belt runs between the ammunition container and the gun.

To take the last point first; in some installations the ammunition container is some distance from the gun and not only is it necessary to provide a chute to guide the ammunition, but in some cases the chute does not follow a straight line but has to be curved and twisted to avoid aircraft structure and so forth. If the chute is excessively long or too sharply curved, the friction between the ammunition and the chute may rise to a figure in excess of the maximum belt pull of the belt feed and cause slack feed stoppages. There is also the possibility, with long chutes, that the friction may be increased due to deflection of the structure under air loads.

These troubles can usually be avoided by careful design of the belt runs and chutes, but the importance of this was not always realised by aircraft designers. Trouble due to insufficient recoil of the gun was experienced with most installations. The recoil spring on the earlier guns was designed so that at 20 mm. recoil it completely absorbed the recoil energy of the gun. If the aircraft structure adjacent to the guns was too flexible it also acted as a recoil spring and absorbed some of the energy that should have gone into the gun recoil spring. This meant that the gun recoil spring did not compress its full 20 mm. and in some cases failed to wind up the belt feed.

The flexibility of the structure was found to vary from one aeroplane to another, and to ensure 100 per cent. recuperation of the belt feed it was necessary to adjust the preloading on the recoil spring of each gun separately. This was a laborious process which had to be repeated each time the guns were changed and was very unpopular with the Royal Air Force. Also, with the spring absorbing all the recoil energy it was found that although the recoil load on the structure was low, usually about 1,500 lb., the energy stored was given out on the run-out of the gun and gave rise to a very high run-out load of the order of 7,000 lb. to 8,000 lb.

In consequence, the recoil spring was redesigned to overcome these objections. In the new design the recoil spring was divided into two parts, a light spring which permitted the gun to recoil 16 mm.-18 mm. and a fairly stiff buffer which permitted a further recoil of 4 mm.-6 mm. but only came into operation after the light spring was fully compressed. This system ensured a consistent recoil of 20 mm. on most installations and did away with the necessity of adjusting the recoil spring for each individual gun.

The new system, however, did not absorb all the recoil energy with the result that the recoil load was increased to 4,000 lb.-5,000 lb. on most installations. It was hoped that this would result in a material reduction in the run-out load, the ideal result being a recoil and run-out load of equal magnitude. In actual fact the results were disappointing and the decrease in the run-out load was not proportional to the increase in the recoil load.

Although the new spring and buffer type of recoil unit was a great improvement on the original, loss of recoil was still occasionally experienced in certain installations. This was due to phasing between the recoil of the gun and the vibration of the aircraft structure under the recoil load, in such a way as to reduce periodically the recoil of the gun relative to the mounting.

These were the major installation troubles experienced with the Hispano 20 mm. gun; there were other minor points which made its installation more difficult than the Browning gun. First was the excessive length of the barrel. In most guns, including both the .303 and .5" Browning guns, the barrel length in terms of calibres is about 72, tending to decrease as the calibre increases; for the Browning 37 mm. gun it is 53.5 and for the Vickers 40 mm. gun 50. For the Hispano 20 mm. gun, however, the barrel length was 85.5 calibres. This length was due entirely to the fact that the original gun had to extend beyond the airscrew boss of the Hispano engine; in a wing installation the gun barrel protruded some distance beyond the leading-edge of the wing.

Also, in addition to being pneumatically fired like the Browning gun, the Hispano gun was fitted with pneumatic cocking. This meant that additional pipe lines had to be carried and also a much greater supply of compressed air. It was found quite early that it was unsafe to recock the Hispano gun after a stoppage and recommence firing. In consequence recocking of wing guns in the air was forbidden and the guns were only cocked on the ground by the armourers previous to take-off. The somewhat elaborate pneumatic cocking system was, therefore, unnecessary.

Although a great improvement on the magazine, the belt feed still made the gun high enough to need a blister on most wing installations and this was a perpetual source of annoyance to the aircraft designer.

Some time in 1942 a requirement was formulated to reduce the weight of all fighter equipment, including armament, in an attempt to obtain the maximum altitude on the latest interception fighters. In view of this the opportunity was taken to carry out a partial redesign of the 20 mm. Hispano gun to reduce its weight and improve its installation characteristics.

First, the length of the barrel was reduced by 12" and the outside diameter also greatly reduced. This meant that on the new installations the barrel did not project beyond the leading-edge and the loss of muzzle velocity resulting from the decrease in barrel length was negligible—some 50 ft. per sec. The pneumatic cocking unit was eliminated and replaced by a detachable hand-operated unit incorporating a 2 to 1 pulley block. The cocking unit became ground equipment, the guns being cocked on the ground before take-off and the cocking unit removed. This eliminated the pipes, etc., which had to be carried on the aircraft for the original gun. The belt feed was also lightened by replacing certain bronze castings with aluminium casting.

The new gun, known as the Mark V, besides being easier to install showed a saving in weight of 25 lb. per gun, with no reduction in performance or reliability. Originally it was also speeded up from 600 r.p.m. to 750 r.p.m., but the phasing troubles between the aircraft structure and gun recoil, already mentioned, became worse with the faster and lighter gun, and for operational use its speed was usually kept to the original 600 r.p.m.

In spite of its teething troubles, from the time of the Hurricane IIc installation onwards the Hispano 20 mm. gun was a serviceable weapon, more reliable than any weapon used in the 1914-18 War, not inferior to any other 20 mm. weapon in service as regards reliability and superior to all as regards weight and performance.

GERMAN 20 mm. CANNON

Whereas the Air Ministry adopted a high velocity 20 mm. projectile from the start and

retained it throughout the war, the Germans used high and low velocity projectiles. A high velocity projectile has greater penetration and is essential for attacking armour. On ordinary structures, engines, etc., the destructive effect of high velocity projectiles is due to the large kinetic energy of the projectile. Low velocity projectiles depend for their destructive power on the explosive charge in the projectile.

The length of a gun mechanism depends on the length of the cartridge case, and the length of the barrel and cartridge case depend on the velocity of the projectile; hence for the same calibre a low velocity gun will be smaller, lighter and have a smaller recoil load than a high velocity gun. This is illustrated in Fig. 4 where cartridge length and gun size are shown diagrammatically as a variable of muzzle velocity.

It also follows that for a given gun weight and size it is possible to have a high velocity gun of one calibre or a low velocity gun of a larger calibre. The projectile of the larger calibre gun would, of course, carry a greater weight of explosive. The main point is whether the target to be attacked is destroyed more easily with a high velocity projectile of low or non-existent explosive content, which depends on its kinetic energy for its destructive power, or a larger low velocity projectile of high explosive content. This is a tactical point which has to be decided by the Air Staff concerned; either type can be designed with equal facility. As already stated the Air Ministry decided on the high velocity projectile.

About the same time as the Air Ministry adopted the Hispano gun the Luftwaffe adopted the low velocity Oerlikon 20 mm. gun. This gun, because of its low velocity, was far smaller than the Hispano and easier to install in an aeroplane as it was little longer than the rifle calibre guns and its weight came midway between the rifle calibre guns and the Hispano. As a result, the Oerlikon gun went into service earlier

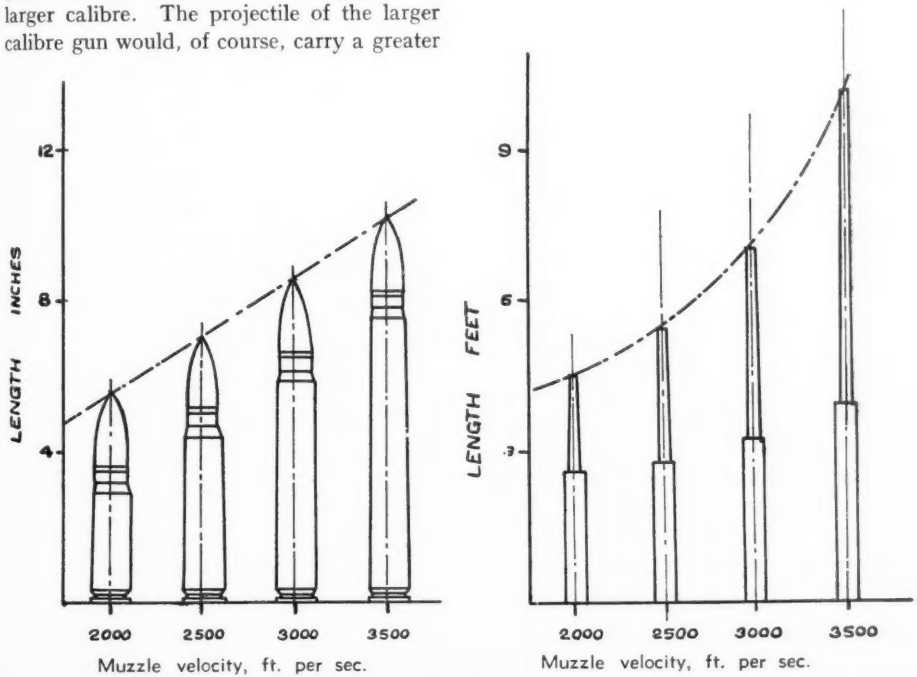


Fig. 4

than the Hispano and Luftwaffe fighters were equipped with it at the outbreak of war.

Its results were, from the German point of view, disappointing; armour sufficient to defeat the German 7.92 mm. Armour Piercing projectile would also defeat the low velocity Oerlikon projectile. Also, the explosive charge was not sufficient to do lethal damage to contemporary aircraft structures. In performance this gun was definitely inferior in every way to the Hispano 20 mm. gun. This was soon realised by the Luftwaffe and some 12 months after the introduction of the Hispano gun into the Air Force a new German 20 mm., the Mauser M.G.151, was introduced into the Luftwaffe, fitted to the F.W.190.

The Germans have always spent far more money on gun design and development than we have and the Mauser factories were world-famous. In consequence, there was always a tendency to exaggerate the merits of German weapons, and this applied fully to the M.G.151. Early reports sugggested that it was superior to the Hispano, being lighter in weight and much faster; it could also be synchronised to fire through the airscrew disc, enabling the gun to be mounted close to the fuselage and thus reducing the rolling movement of inertia. Examination of captured guns did not fully substantiate these claims.

First, the gun was lighter than the Mk. II Hispano, but the projectile had a lower velocity—2,600 ft/sec. against the 2,800 ft. per sec. of the Hispano. As already pointed out, this gives a shorter and lighter gun. The M.G.151 was definitely easier to install than the Hispano as it did not recoil relative to the aircraft structure; it was also neater in appearance and of smaller overall dimensions owing to the fact that it had a built-in belt feed.

These advantages were partly offset, however, by the very elaborate electric recocking system and taking this into consideration it is doubtful if, considered as a complete installation, it was as much lighter or easier to install compared with the Mk. II Hispano as would at first appear.

As regards rate of fire the most the M.G.151 ever gave on test was 680 r.p.m. compared with the 600 r.p.m. of the Mk. II Hispano. The electric firing of the M.G.151 enabled the gun to be synchronised with the airscrew, but this entailed the use of an electrically initiated cap on the ammunition. This gave a lot of trouble in the early days and was never as reliable as the normal percussion cap.

Another unsatisfactory feature was the type of belt used. This was similar to that used in the M.G.17 but was made to disintegrate at every fifth link. This belt was inferior to the Hispano belt and more difficult from the installation point of view, both as regards design of link chutes and disposal of the empty belt.

Considering the troubles likely to develop with the electric cocking gear, electric cap and the belt it is very doubtful if the M.G.151 was as reliable as the Hispano gun. The M.G.151 was also more difficult to produce than the Hispano gun, and compared with the Mk. V Hispano, was definitely inferior in performance and weight.

Although the 20 mm. Hispano gun was the standard fighter armament, one other gun was used on a small scale for air to ground attacks. This was the Vickers 40 mm. "S" gun, the so-called "Tank-Buster." It was fitted to a Hurricane and was intended for the attack of armoured fighting vehicles.

In contrast to the Hispano gun, this weapon gave very few installation troubles. It had a self-contained and very efficient recoil system, the recoil and run-out loads being no higher than for the Hispano gun. This was possible owing to the slow rate of fire of the gun, some 100 r.p.m., which allowed plenty of time for the recoil energy to be absorbed. As the gun body did not recoil, the attachment of the gun to the aircraft was very simple and consisted of two bolts similar to the Browning gun. The

installation was also simplified by the fact that the gun was carried externally, being slung under the wing like a bomb. The pneumatic firing made no greater demands on the aircraft designer than the Hispano installation and the gun was cocked on the ground by hand.

One interesting fact about this gun was that because of the comparatively high momentum of the projectile and its underslung position, simultaneous firing of the two guns caused a change of trim of the aircraft.

It will be apparent that many of the installation troubles of the Hispano 20 mm. gun were due to the fact that the gun was designed for mounting on a Hispano Suiza engine and the typical wing installation used in the R.A.F. had not been foreseen or catered for by the gun designer.

The M.G.151 on the other hand was designed specifically for wing installation. As would be expected, it was an easier gun to install than the Hispano and was of small overall dimensions. In spite of this, however, when comparing the M.G.151 with guns of similar calibre used by the German Army, there is no doubt that, like all other aircraft guns so far designed, it is fundamentally a Land Service weapon modified for air use. The type of belt used is a case in point; it is unsatisfactory from an aircraft installation point of view and compares unfavourably with the Hispano and Browning Belts. This form of belt, however, represents an easy solution of the feed problem for the gun designer and is quite satisfactory for Land Service.

CONCLUSIONS

The conditions under which a gun is used vary immensely between the Air Service and the Land Service. A Land Service weapon of the comparable calibre is designed to be a self-contained unit, that is manhandled in action by a gun crew. The conditions in the wing of an aircraft are very different; there is no reason why guns should be self-contained units, but in action they must function reliably without any human attention.

One of the most persistent troubles in all automatic guns is the feeding of the belt into the gun. For land use, when the gun must be a self-contained unit, the feed mechanism is always driven from the internal energy of the gun. Whether gas pressure or recoil energy is used, it is always applied in a violent form as a shock load and is very difficult to translate into a smooth movement of the belt. In an aircraft gun there is no reason why the belt feed should not be driven by some external source of power. An electrically-operated feed was actually designed for the Hispano Gun and was very successful. It could not be applied to existing aircraft, however, as the current required was not available.

Ammunition design is even more conservative than gun design and more completely identified with Land Service conditions. The .303 calibre ammunition, which was the only ammunition used in aircraft until late 1940 and remained the main bomber defence till the end of the war, was originally designed for the Lee Enfield Rifle, introduced in 1902. Although subject to a number of modifications, mainly to the projectile, there has been no fundamental change in this ammunition.

It is suggested that the time has now come for gun designers to break with Land Service traditions and consider aircraft guns purely as aircraft equipment, taking full advantage of the more favourable conditions appertaining to aircraft installations. This would make possible a considerable advance in aircraft gun design, especially as regards rate of fire and reliability.

CORRESPONDENCE

ON DR. REDSHAW'S PAPER. *20th August*, 1946.

In the August 1946 Journal an account of Dr. Redshaw's lecture on "The Electrical Measurement of strain" was given. I wish to draw attention to an incorrect statement by Dr. Redshaw in his reply to the discussion.

Replying to Mr. Taylor of the R.A.E., Dr. Redshaw stated "The method of using two gauges at right angles and at 45° to the required direction of shear was a useful method only if the principal axis of strain were known," and again in this reply "it would not be sufficient to place two gauges at 45° to a direction along which a shear strain was required."

This view is incorrect and it may be demonstrated quite simply that in fact two gauges at 45° to a given direction can be used to measure the shear strain.

Let us define (in two dimensions) the strains to be given by:—

$$e_{xx}=\frac{\partial u}{\partial x};\ e_{yy}=\frac{\partial v}{\partial y};\ \text{and}\ e_{xy}=\tfrac{1}{2}\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)$$

The shear strain e_{xy}, thus defined, will be half that used by Love and others and is adopted here, as it is by Dr. H. Jeffreys and Professor S. Chapman, because when so defined the strain components constitute a "strain tensor" and components obey the laws of tensor transformation. This does not affect the point at issue.

If $e_{\Gamma\Delta}$ be any component of strain referred to the co-ordinates OX, OY, and if $e_{\alpha\beta}$ be any component of strain at the same point referred to any other co-ordinates Ox, Oy, we shall have

$$e_{\Gamma\Delta}=\frac{\partial\Gamma}{\partial\alpha}\frac{\partial\Delta}{\partial\beta}e_{\alpha\beta}$$

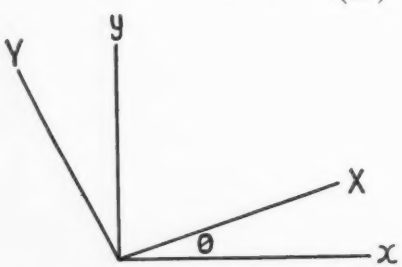
in the notation of the Tensor Calculus, α and β being repeated, they are summed for all possible values (x and y).

We thus get three equations:—

$$e_{xx}=e_{xx}\left(\frac{\partial X}{\partial x}\right)^2+2e_{xy}\frac{\partial X}{\partial x}\frac{\partial X}{\partial y}+e_{yy}\left(\frac{\partial X}{\partial y}\right)^2,$$

$$e_{xy}=e_{xx}\frac{\partial X}{\partial x}\frac{\partial Y}{\partial x}+e_{xy}\left(\frac{\partial X}{\partial x}\frac{\partial Y}{\partial y}+\frac{\partial X}{\partial y}\frac{\partial Y}{\partial x}\right)+e_{yy}\frac{\partial X}{\partial y}\frac{\partial Y}{\partial y},$$

$$\text{and}\ e_{yy}=e_{xx}\left(\frac{\partial Y}{\partial x}\right)^2+2e_{xy}\frac{\partial Y}{\partial x}\frac{\partial Y}{\partial y}+e_{yy}\left(\frac{\partial Y}{\partial y}\right)^2.$$



Clearly $\frac{\partial X}{\partial x}=\cos\theta$; $\frac{\partial X}{\partial y}=\sin\theta$;

$\frac{\partial Y}{\partial x}=-\sin\theta$; $\frac{\partial Y}{\partial y}=\cos\theta$.

Then if we choose $\theta=45°$, we have

$$e_{xx}=\tfrac{1}{2}e_{yx}+e_{xy}+\tfrac{1}{2}e_{yy},$$

$$e_{xy}=-\tfrac{1}{2}e_{xx}+\tfrac{1}{2}e_{yy},$$

and

$$e_{yy}=\tfrac{1}{2}e_{xx}-e_{xy}+\tfrac{1}{2}e_{yy}.$$

The second equation shows that the shear strain e_{xy} depends only upon the measure-

ment of e_{xx} and e_{yy}, and by taking the difference between the first and third the shear strain e_{xy} depends only on the measurement of the direct strains e_{xx} and e_{yy}.

The axes are not preferential in any way and even if the OX, OY axes are assumed principal the others could not be, but the same relation between the strains occcurs.

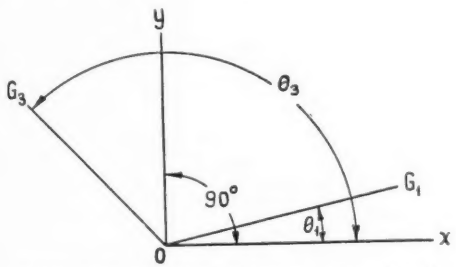
JOHN K. REDMAN (Associate Fellow).

Dr. REDSHAW'S REPLY: *17th September*, 1946

Mr. Redman is quite correct in his statement that I made an error in my reply to Mr. Taylor's contribution to the discussion on my paper, and I am grateful to him for calling my attention to it.

My comment was based on an article by Mr. J. C. King[1] of the Royal Aircraft Establishment, in which he discussed the use and limitations of the two gauge rosette.

It seems to me that Mr. Redman has complicated his proof quite unnecessarily by the introduction of the tensor calculus.



In the accompanying sketch let OG_1 and OG_3 denote any two directions, along which strain gauges are attached, making angles of θ_1 and θ_3 respectively with the x axis of a rectangular co-ordinate system of axes.

The fundamental equation for a strain rosette is[2, 3]

$$\epsilon_\theta = \epsilon_x \cos^2\theta + \epsilon_y \sin^2\theta + \gamma_{xy} \sin\theta \cos\theta \quad (1)$$

From this equation the strains in the direction of the gauges G_1 and G_3 may be written as follows

$$\epsilon_1 = \epsilon_x \cos^2\theta_1 + \epsilon_y \sin^2\theta_1 + \gamma_{xy} \sin\theta_1 \cos\theta_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\epsilon_3 = \epsilon_x \cos^2\theta_3 + \epsilon_y \sin^2\theta_3 + \gamma_{xy} \sin\theta_3 \cos\theta_3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now if

$$\theta_1 = 45^\circ \text{ and } \theta_3 = 135^\circ,$$

equations (2) and (3) reduce to

$$\epsilon_1 = \tfrac{1}{2}(\epsilon_x + \epsilon_y + \gamma_{xy}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$\epsilon_3 = \tfrac{1}{2}(\epsilon_x + \epsilon_y - \gamma_{xy}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Solving equations (4) and (5) for γ_{xy}, the required shear strain, we have

$$\gamma_{xy} = \epsilon_1 - \epsilon_3. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

That is to say, the shear strain in a given direction may be determined from the direct strain readings of two gauges mounted at right angles to each other, each making an angle of 45° to the direction along which the shear strain is required.

As I stated in the discussion, for the complete determination of the strains at a point three gauges would be required.

S. C. REDSHAW, Fellow.

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[1] J. C. King: Strain Gauge Rosette Formulæ. Aircraft Eng. Feb. 1944, p. 37.
[2] M. M. Frocht: Photoelasticity, Vol. 1, p. 36.
[3] A. E. H. Love: A Treatise in the Mathematical Theory of Elasticity. 3rd Edition, p. 40.

ON DR. REDSHAW'S PAPER:

In Dr. Redshaw's reply to my contribution to the discussion of his paper on "The Electrical Measurement of Strain" (p. 611, August 1946 Journal), by implication, he asks how my rearrangement of the components in his Fig. 12, p. 584 effects an improvement.

The main advantage is that with my suggested rearrangement one terminal of the gauge is at earth potential. The maximum potential difference to which any part of the gauge insulation is subjected is therefore the potential across the gauge winding. With his arrangement the *least* potential to which the insulation is subjected is several times that across the gauge because the only interpretation of "large resistor" is large compared with the gauge resistance. As Dr. Redshaw, in his reply to Mr. Clark, p. 610, refers to the danger of insulation breaking down if gauge resistance is increased (his wording) I think he must admit the value of my proposed arrangement of the same components on this ground alone.

There is a second advantage in many practical installations. The "battery" may not be ideal but may contain "noise." If S is the resistance of the gauge and L that of the large resistor, with his arrangement the fraction of the noise which is applied to the amplifier is $L/(S+L)$. With my arrangement it is $S/(S+L)$. The ratio of these is L/S.

I would take this opportunity of accepting Dr. Redshaw's correction regarding gauges "moulded between . . . bakelised paper." Unfortunately I quoted from the wrong paragraph of his paper and I intended to refer to "the winding method of manufacture." As regards my remarks on the question of absolute gauge resistance, these were included, at the suggestion of the Editor of the Journal, as representing a résumé of the relevant part of my reply to the discussion cited (at Inst. Mech. Eng.) and I am sorry that Dr. Redshaw has interpreted them as being primarily directed at himself. But since he appears to agree with me on the essentials involved I can only say that I think that his wording is unfortunate. On p. 583 he says "The cathode ray oscilloscope, which operates on voltage . . . " ; and on p. 584 "it is desirable to have as large a current as possible to pass through the galvanometer." Without my comments I think there would have been appreciable risk of his wording being interpreted in the manner which, I suggest, can lead to false reasoning.

Finally, unless his Fig. 14 is so diagrammatic as to make some additional comments desirable, I cannot agree that quadrature balance in this case is "merely a refinement." Nor do I agree, if by "increase in amplitude" (p. 612) he means increase in envelope amplitude, that this is proportional to strain in the presence of appreciable quadrature unbalance.

F. AUGHTIE, Engineering Division, National Physical Laboratory.

Dr. REDSHAW'S REPLY:

In my reply to Dr. Aughtie's previous comment on the circuit of Fig. 12, I did not disagree with the suggestion that the large resistor and the strain gauge could be interchanged.

Although the reasons offered by Dr. Aughtie for the change are theoretically absolutely correct the practical effect is, I maintain, negligible. If the gauge insulation is unable to withstand the potential to which it is subjected in my system, then the gauge should be discarded as being unsatisfactory.

With regard to battery noise, I am most surprised at the suggestion that any trouble would be experienced in this connection, especially as dry batteries are normally used.

The only other point in Dr. Aughtie's letter which calls for a further reply is his insistence on quadrature balance for the circuit of Fig. 13. Any necessity for quadrature balance can only be caused by the lack of balance in the capacitance of the leads connecting the strain gauges to adjacent-arms of the Wheatstone bridge circuit; in effect a condenser is placed in parallel with each strain gauge. The bridge arms are closely balanced for resistance, the leads being kept as short as possible and carefully matched so as to avoid thermo-electric effects. Furthermore, the frequency of the carrier wave is in the low audio-frequency range, the values of 1,000-5,000 c.p.s. quoted on p. 595 of my paper being typical.

In the circumstances outlined above I think it can clearly be seen that quadrature balance is a refinement. If a carrier wave of radio frequency was used, quadrature balance would be necessary but I have nowhere in my paper suggested that high frequencies of this order should be used.

The proof of the cake is in the eating, and I suggest that anyone who is in doubt regarding the use of the circuits I have described would find the truth for themselves by a simple trial in their own laboratories.

S. C. REDSHAW, Fellow.

ON THE GAS TURBINE DISCUSSION:—

On Fig. 11 of his paper, "The Application of the Gas Turbine to Aircraft Propulsion" (p. 308, May 1946 Journal), Dr. Hooker showed how the propulsive efficiency varied with the forward speed of the aircraft, and that for the simple jet propulsion engine the maximum efficiency is of the order of 62 per cent at 600 m.p.h.

With "Reflex Reaction Propulsion"* this criterion does not apply and the propulsive efficiency is of the same order as that of the turbine, since the same laws that govern the design of the turbine govern reflex reaction propulsion design, except that in the latter case, the propulsive gases and the deflectors are moving in the same direction with the same forward velocity, and the efficiency does not fall off as the velocity of the aircraft increases or decreases.

This system is already in operation on the centrifugal compressor of the Rolls-Royce Derwent where the air is deflected through an angle of above 90° on leaving the diffuser for the combustion system.

If we take, for example, the velocity of the air at this point as being in the region of 250 feet per second, and the deflection as being 90° in the horizontal direction, the centrifugal force reaction created by deflecting one pound of air per second at this velocity, will be:—$R = (wv/g)\sqrt{2} = (1 \times 250/32.2) \times 1.414 = 10.9$ lb. acting at 45° to the horizontal and the component thrust force acting in the line of flight will be: $F = R \cos 45° = 10.9 \times .7071 = 7.76$ lb. and the useful force may be improved by suitable design work.

It is well understood that the propulsive forces created by the propeller take effect through the thrust bearing and are thence transmitted to the engine and the body of the aeroplane to which it is fixed, but it is not so clearly understood at which corresponding points the jet reaction forces take effect. Perhaps Dr. Hooker would enlighten us as far as the Derwent is concerned.

Reflex reaction may be extended almost as far as the final exhaust nozzle, provided that the deflections and gas accelerations are correctly interrelated and the efficiency will not decrease to anything like 62 per cent. and we are not yet using all the thrust available.

*By "reflex reaction propulsion" is meant propulsion due to the reaction or reflection of, or from, a force created centrifugally by the mass gas stream flowing around a bend or elbow.

Turning to Dr. Ricardo's paper, "Turbine Compounding of the Piston Aero-Engine" (p. 323, May 1946 Journal), I would like to ask if he has considered the twin cylinder side-by-side common combustion chamber two-stroke engine for his scheme. This design will give larger inlet and exhaust parts with better timing than the loop scavenge engine, for less weight than the double crank opposed piston engine.

Touching upon Mr. Carter's paper "The Application of Jet Propulsion to Military Aircraft" (p. 347, May 1946 Journal). The frontal area in square feet is most important, but linked up with this is the impeller intake area in square feet.

The velocity of the air at the impeller intake, both axial and centrifugal, may be of the order of 500 feet per second at sea level, and this velocity increases with altitude to high Mach numbers.

Where we assume an air velocity at the intake of 500 ft./sec. the weight of air entering the impeller will be about 38.8 lb. per sq. foot per second, at sea level; and if the engine gives a static thrust of 50 lb. per pound of air per second, there will be 1,940 lb. of thrust per square foot of compressor intake area.

With the double-sided centrifugal compressor we stand to gain in intake area, for a given size, as well as in thrust efficiency; thus the frontal and intake areas must be a balanced compromise in all cases, with an elementary condition in favour of the double-sided centrifugal.

The compressor-turbine-propeller combination has also received the writer's attention and the results exceed Mr. Pilling's requirements; the writer's design requires no reduction gears and their consequent weight and troubles are avoided, while at the same time retaining the efficient reflex reaction in full.

The writer uses, in some designs, the radial outward flow turbine which, while it is perhaps more limited in its scope than the axial, is better cooled and is able to carry higher gas temperatures than the axial, and it is suited to plants for the small private owner aeroplane.

These probabilities yet remain to be demonstrated, and I have been calling for their demonstration for the past five years, without results; this is a much longer period than would be required to build and test a prototype model.

F. UMPLEBY.

Dr. RICARDO'S REPLY:

I did consider very carefully the possibilities of the twin-cylinder side-by-side common combustion chamber type, but, although there is much to be said in favour of this form of engine I decided against it on the grounds:

(1) That we have never been able to devise for this type a satisfactory form of combustion chamber for use with compression ignition.

(2) If the passage-way between the two cylinders is adequate for efficient scavenging, without undue pressure drop, then the volume enclosed is too great to be compatible with the fairly high ratio of compression required.

(3) On the purely mechanical side this form involves either two crankshafts in parallel on close centres or a somewhat long and lanky shaft, neither of which is desirable.

H. R. RICARDO, F.R.S., Fellow.

Editor's Note—Dr. Hooker is abroad.

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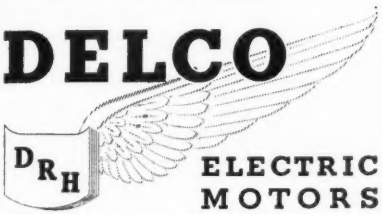

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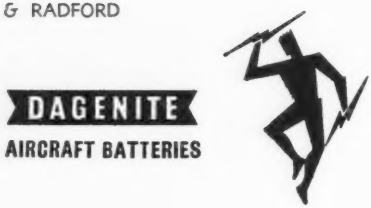

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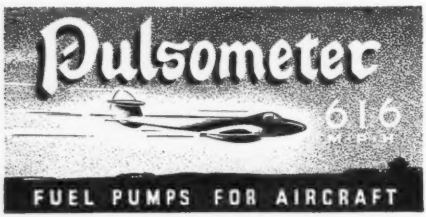

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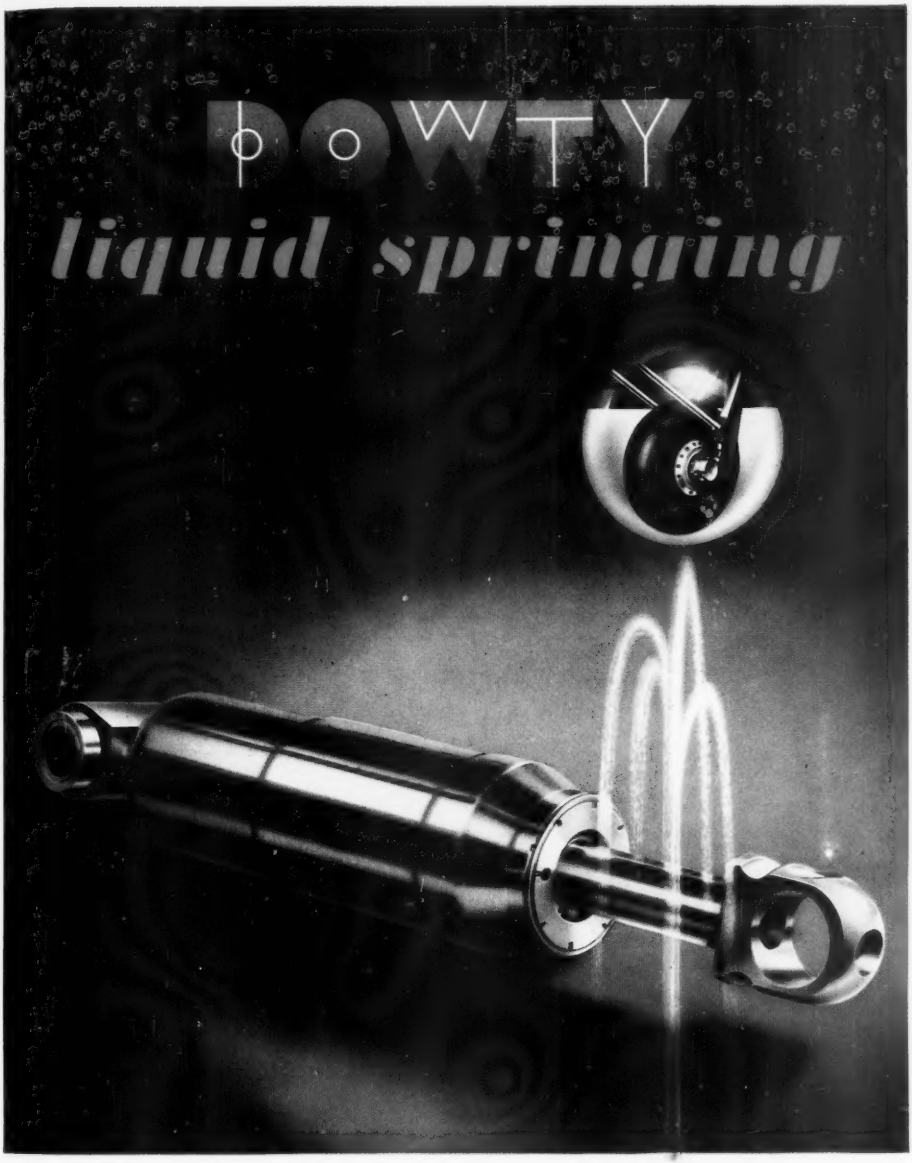

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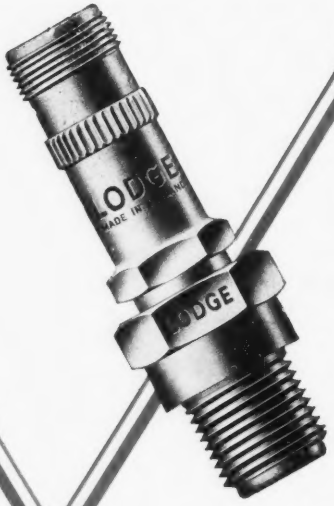

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JULY NOTICES 1946

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

Contents of July Journal

Critical Review of German Long-Range Rocket Development, by W. G. A. Perring, F.R.Ae.S.

The Design and Production of Japanese Military Aircraft, by Alex. P. West, A.F.R.Ae.S.

Book Reviews.

Meeting of Council

At the 564th Council Meeting held on Thursday, 30th May, 1946, the following were present:—E. J. N. Archbold, Sir John Buchanan, Major G. P. Bulman, S. Camm, G. P. Douglas, W. S. Farren, Sir A. H. Roy Fedden (Past President), A. Gouge (Past President), E. T. Jones, Sir Ben Lockspeiser, Major R. H. Mayo, N. E. Rowe, Sir Oliver Simmonds (Vice-President), and Captain C. F. Uwins (Honorary Treasurer).

Among the business transacted was the following:—

The Council passed the report of the Grading Committee recommending the list of Associate Fellows and Companions for election.

The Council adopted the recommendations of the Technical Committee and in particular agreed that the Society should be represented officially, by one of its members, at the International Congress of Applied Mechanics in Paris in September.

The Council passed the reports of the Finance Committee and Journal Committee and agreed to the recommendation of the Education and Examinations Committee that the new syllabus for the Associate Fellowship examination should be put into force on 1st January, 1948.

It was agreed that Sir Oliver Simmonds should represent the Society on the Engineering Joint Council and Sir Frederick Handley Page should represent the Society on the Institution of Mechanical Engineers, National Certificates and Diplomas in Mechanical Engineering Committee. It was agreed that representatives on other bodies should be re-elected.

The Council appointed the following Committees and Sub-Committees to hold office during the lifetime of the present Council:—Technical Committee, with Sub-Committees on Structures, Aerodynamics, Engines and Materials; Lectures and Debates Committee; Publications Committee; Examinations Committee; Grading and Awards Committee; General Purposes Committee, with Sub-Committees on Rules, Membership, Library, Garden Party and Lecture Hall; Finance Committee; and Branches Committee.

Representatives on Other Bodies

Advisory Committee for Aeronautical Engineering of the City and Guilds of London Institute:—Professor F. T. Hill and Captain J. L. Pritchard.

Association of Special Libraries and Information Bureau:—Mr. J. E. Hodgson (Honorary Librarian).

British Standards Institution Aircraft Committee:—Sir Roy Fedden and Mr. A. Gouge.

British Standards Institution Jewels and Bearings Committee:—Major Shilson.

Engineering Joint Council:—Sir Oliver Simmonds.

Engineering Joint Council—Special Education Representative:—Professor G. T. R. Hill.

National Central Library:—Mr. J. E. Hodgson (Honorary Librarian).

Institution of Mechanical Engineers, National Certificates and Diplomas in Mechanical Engineering:—Sir Frederick Handley Page and Professor F. T. Hill.

General Board of National Physical Laboratory:—Mr. W. C. Devereux and Mr. A. Gouge.

College of Aeronautics:—Sir Roy Fedden and Dr. H. Roxbee Cox.

British Gliding Association, Research Committee:—Mr. G. H. Lee.

Paris International Technical Congress

Members of the Society are invited to attend the International Congress which is to be held in Paris from September 16th to the 21st, 1946.

The Congress is open to all engineers and members of Allied professions and will be held in the "Maison de la Chemie" 28, bis, rue Saint-Dominique, Paris (7e). It is being organised by a Committee of French engineers set up by the co-operating countries. These include Belgium, Canada, China, Czechoslovakia, Denmark, Egypt, France, Great Britain, Greece, Luxembourg, Norway, Portugal, Sweden, Switzerland and the United States of America. Scientists, engineers and architects from those countries will present papers.

The provisional programme provides for papers under four main headings:—A. General Engineering Problems of Reconstruction and Economic Development in the World; B. Atomic Energy; C. Present situation of engineering in the World; and D. Engineers in the World.

The fee for attending the Congress is four guineas per member. This entitles the subscriber to attend all lectures, take part in the discussions and receive copies of all papers presented. Advance resumés of papers are expected to be available for those who wish to take part in the discussions.

Travel agencies have been appointed by the Congress to advise and assist those wishing to attend on travel and hotel arrangements, including passports and visas.

The number of participants from each country to the Congress is restricted and members of the Society who wish to attend should apply to the British Committee without delay. The address is: Robert Lowe, Organising Secretary, British Committee of International Technical Congress, 82, Victoria Street, London, S.W.1.

The members of the British Committee are:—W. R. Howard, Esq., M.I.Struct.E., M.S.E., M.Soc.C.E. (France), Chairman; Brian H. Colquhoun, B.Sc., M.Inst.C.E., M.I.Struct.E., M.Soc.C.E. (France), Hon. Treasurer; Frank Parfett, F.S.E., M.Soc.C.E. (France), Hon. Secretary.

Vacancy on Society's Technical Staff

A vacancy exists on the Society's Technical Staff for someone to prepare Data Sheets on performance.

Applications, stating qualifications and experience, should be received by the Secretary not later than the 15th July.

History of the Society

An illustrated history of the Society has been prepared covering the first eighty years 1866-1946. The history contains many remarkable references to and extracts from the early proceedings of the Society, showing how its members played an astonishing part in the development of flight, from initiating the earliest wind tunnel experiments in the world and the first discussion, nearly sixty years before the event, on jet propelled aircraft, to the most modern developments.

It is hoped that every member will acquire a copy of this history, of which only a limited edition has been printed. It can be obtained from the offices of the Society price 5/3 post paid.

Changes of Address

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Graduates' and Students' Section

A visit has been arranged to the works of Short Bros. (Rochester and Bradford), Ltd., at Rochester on Saturday, 17th August. Applications to attend should be sent to the Hon. Secretary, J. G. Roxburgh, 62, Fitzjohn Avenue, N.W.3, and must be received at least one week before the date of the visit.

Branch Activities

HATFIELD BRANCH

A visit has been arranged to the Bristol Aeroplane Co., Ltd., at Bristol on Friday, 12th July, and, also on the 12th July, to Short Brothers (Rochester and Bedford), Ltd., at Rochester.

LEICESTER BRANCH

The temporary Hon. Sec. of the Leicester Branch is R. Holl, Esq., c/o Power Jets (R. & D.), Ltd., Whetstone, Leicester.

Election of Members

The following members have been elected recently:—

Fellows (From Associate Fellows)

John Parkyn Jeffcock, Ernest Wesley Clare Wilkins.

Associate Fellows

John Douglas Bennett (from Student), Wilfred Michael Bentley (from Graduate), James Gordon Dawson, Cyril Albert Elliott, Yehoshua Gilutz, Alan Greaves (from Graduate), Henry Llewellyn Hackforth (from Graduate), Percy Howlett (from Student), Philip Gordon Harwood (from Graduate), Allan Thomas Oswald Liddell, Leonard John Ludlam, John Stanley Mason, Eric George Monk, Eric Stanley Moult, Thomas George Garrood Newbery, Zeev Wolf Segal, Norman Harry Shuttleworth, Philip Simpson, Richard Denbigh Starkey, Keith Watson Todd, Geoffrey Robert Venn-Brown, Lucien Sidney Wigdortchik (from Graduate), Kenneth Grahame Wilkinson.

Associates

Ernest Wilfred Aldrich, John Austin, Frank William Barnes, Roland Prosper Beamont, Ivor Albert William Bowman, Derek Martin Butcher (from Student), Kenneth John Cheese, John Dudley Coates, Aubrey George Corbin, Denis Ridley Cox, Joseph Cross, William Arthur Daunt, Kenneth Campbell Derrick, Szymon Boguslaw Dowkontt, Christopher William Driscoll, Thomas William Ellcock, Geoffrey Cyril Ellis, David Jeffrey Goman (from Graduate), Gustaf Gudmundson, Ronald Ainsworth Halliday, John Frederick Handasyde, James Dodsworth Hannington, Ronald Owen Hender (from Graduate), Frederick Reginald Stanley Holben, Cyril Jones (from Student), Robert Frederick Jones, Edward George King, John Joseph Lindsay (from Student), Ronald James McWilliams, John Everard Hadfield Marshall, George Alexander Michailov, William George Montgomery, Percival Guy Haig Newton, Ralph Edward Pettet, Henry Lewis Pugh, Cyril Henry Russell, Derek Robert Samson (from Student), John Henry Sewell, Stanley Bernard Simpson (from Graduate), Raymond William Henry Stevenson (from Graduate), William Sturrock, Cecil Rendle Tapper, Ronald Teiford, Albert Victor Thomas, Harold Tongue, John Hawthorne Troughear, Jack Weston, William James Wilkinson, Albert Stannard Wilshere.

Graduates

Leslie Alcock, Harvey Buckley, Michael Cullen Campion, Hassanand Rijhumal Chablani, Maurice Cecil Curties (from Student), Sydney Davis (from Student), John Yarath Gwynne Evans, James Fletcher (from Student), Joseph Cyril Guttridge (from Student), Derek Thomas Hine, George Jackson, Dennis James Moore (from Student), Michael David Mugford (from Student), Norman Nash (from Student), Samuel George Robbins (from Student), Paul Terence Ernest Rowan, Anthony Arnold Seal (from Student), Anis Rateb Sidrak, Rupert d'Egville Smuts, Reginald David Swift, Hugh Wason Turner.

Students

John Sidney Bastable, James Hutton Boyd, John Alfred Bridges, Arthur John Cable, David Eric Chandler, Kenneth John Coleman, Donald Louis James Corner, Sunil Ranjam Das Gupta, Jack Glyn Davies, Roger Anthony Grimston, Donald Reginald Henbest, Harold Hoke, John Howell, Rex Richard Howlett, Walter Bryden Salsbury, Cecil James Smith, Kenneth James Staples.

Companion

Robert Percival Craigen.

Acknowledgements

The Council acknowledge with grateful thanks the gift of a book from Arthur J. Hughes, Esq., and a First Day Air Mail Cover from A. B. Coates, Esq.

Additions to Library

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

A.a.316.—Aerodynamics. N. A. V. Piercy. English Universities Press. 1946.

A.a.317.—Treatise on Dynamics. A. and J G. Grey. Macmillan. 1911.

D.b.254.—Air Travel Digest. Combinair, Ltd. 1945.

D.b.255.—Merchant Airmen. Air Ministry. H.M.S.O. 1946. 2/-.

E.c.27.—*Application of double fourier series to the calculation of stresses caused by pure bending in a circular monocoque cylinder with a cut out.* Zbigniew Krgywoblocki. Polish Institute of Arts and Sciences in America. 1946. (Y.8.)

EE.c.80.—Aeroplanes and Aero-engines. 3rd edn. Captain P. H. Sumner. Technical Press. 1939.

EE.e.20.—Principles of Ignition. J. D. Morgan. Pitman. 1942.

EE.h.18.—Jet Flight. John Grierson. Sampson Low, Marston. 1946.

H.b.90.—Business Law of Aviation. Gerald O. and Lillian G. Dykstra. McGraw-Hill. 1946.

K.c.24.—World Power and Atomic Energy. H. E. Wimperis. Constable. 1946.

L.d.112.—Navigation. S. F. Card. Edward Arnold. 1915.

L.d.113.—History of Air Navigation. Arthur J. Hughes. Allen & Unwin. 1946.

**R.b.258.—Tableau Historique des Propriétiés et des phénomènes de l'air. M. Rouland. Gueffier. Paris. 1784.

T.b.97.—The Spider Web. P.I.X. Blackwood. 1919.

T.b.98.—North to the Orient. Anne Morrow Lindbergh. Harcourt Brace. N.Y. 1935.

UF.5.—*International Commission for Air Navigation. Bulletin No.* 27. February, 1940. I.C.A.N. Paris.

UH.6.—*Convegno di Scienze Fisiche, Matematiche e Naturali. Tema: Le Alta Velocità in Aviazione.* Reale Academia d'Italia, Rome. 1936.

UH.7.—*Il Terrorismo Aereo nella teoria e nella realta.* Raffaele Giacomelli. Associazione Italiana d'Aerotecnica. 1945.

V.1.26.—Transactions of the American Society of Mechanical Engineers. Vol. 67. 1945. A.S.M.E. 1946.

J. Laurence Pritchard, *Secretary.*

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TECHNOLOGY DEPT.

THE ROYAL AERONAUTICAL SOCIETY

4, HAMILTON PLACE, PICCADILLY, LONDON, W.1

AUGUST NOTICES 1946

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

Contents of August Journal

Atomic Disintegration, by Professor N. Feather, Ph.D., F.R.S.

The Electrical Measurement of Strain, by S. C. Redshaw, M.Sc., Ph.D., M.Inst.C.E., F.R.Ae.S.

The Expanding Domain of Aeroelasticity, by Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S.

Council Meeting

A meeting of Council was held on Thursday, 27th June, 1946, at which the following were present:—Sir Frederick Handley Page (President) in the chair, E. J. N. Archbold, Lord Brabazon, Sir John Buchanan, Major G. P. Bulman, Dr. H. Roxbee Cox (Vice-President), G. P. Douglas, W. S. Farren, E. T. Jones, Sir Ben Lockspeiser, Major R. H. Mayo, N. E. Rowe, Sir Oliver Simmonds (Vice-President), Captain C. F. Uwins.

(In the account of the Council meeting of 30th May in the July Journal Sir Frederick Handley Page's name was inadvertently omitted from the list of those present).

Among the business transacted was the following:—

The Journal, Lectures and Debates, Education and Examinations and Grading Committees were appointed for the year 1946-47.

The reports of the Finance, Education and Examinations, Grading, Journal, General Purposes and Technical Committees were considered and adopted.

The following sub-committees were appointed under the General Purposes Committee: Rules Committee, Advisory Committee and Membership Committee.

President

At the meeting of Council on 27th June, 1946, Sir Frederick Handley Page was elected President for a second term, beginning October, 1946, and ending September, 1947.

Vice-Presidents

At the meeting of Council on 27th, June, 1946, the following were elected Vice-Presidents of the Society for the year 1946-47:—Sir Oliver Simmonds, Dr. H. Roxbee Cox and Mr. N. E. Rowe.

Garden Party

The Society will hold a Garden Party at Radlett Aerodrome on Sunday, 15th September, 1946.

It has been possible to make the necessary arrangements for the Garden Party by the kindness of the Society of British Aircraft Constructors and the President, Sir Frederick Handley Page.

NOTICES

The Society of British Aircraft Constructors are holding their Flying Display and Exhibition at the Handley Page Aerodrome, Radlett, Hertfordshire, and they and the aircraft companies concerned have generously agreed to keep the Display and Exhibition in being especially for members of the Society and their friends.

Two hundred British companies, manufacturers of aircraft, aero-engines, propellers, instruments, components and materials, will show their products. Modern types of commercial and combat aircraft will also be shown, as well as the latest power plants, both piston and gas turbine units, and there will be a flying display.

The President of the Society, Sir Frederick Handley Page, has kindly consented to make the aerodrome available to the Society's members and their guests for the day.

The Display will begin at 2.30 p.m. and end at 7.30 p.m.; and tea will be served to members and their guests. Admission will be by ticket only, obtainable only through a member of the Society.

The number of tickets available will be limited and application should be made as early as possible to avoid disappointment. Each member will be allowed a maximum of four tickets in all, one for himself and three for guests. The price of the tickets will be 7/6 each. A car park will be available for those who come by road.

The Birthday Honours List

C.B.E. (Military Division)

Group Captain C. Rapley, R.A.F., Associate Fellow.
Group Captain H. J. Wilson, A.F.C., R.A.F., Associate.

C.B.E. (Civil Division)

R. E. Bishop, Esq., Associate.
Harold Grinsted, Esq., O.B.E., Fellow.
Captain A. G. Lamplugh, Fellow.

O.B.E. (Military Division)

Wing Commander E. L. T. Barton, R.A.F.V.R., Associate Fellow.
Wing Commander M. D. Day, R.A.F., Associate.
Lieutenant Commander (E.) C. C. Mitchell, R.N.V.R., Associate Fellow.
Wing Commander V. C. Otter, R.A.F., Associate.

O.B.E. (Civil Division)

A. B. Barbour, Esq., M.R.C.S., L.R.C.P., Associate Fellow.
E. S. Greenwood, Esq., Associate.
S. G. Hooker, Esq., D.Phil., Associate Fellow.
Wing Commander (Acting Air Commodore) the Hon. W. L. Runciman, A.F.C., Companion.
D. N. Walker, Esq., A.M.I.Mech.E., M.I.A.E., Associate Fellow.
G. O. Waters, Esq., Associate.

M.B.E. (Military Division)

Mr. W. R. Booley, Temporary Acting Commissioned Aircraft Officer, R.N., Associate.
Lieutenant (A.) (A.E.) H. A. Jarrett, R.N., Associate.
Squadron Leader F. C. Woolley, R.A.F., Associate.

M.B.E. (Civil Division)

Sydney Oldfield, Esq., Associate.

C. H. Webb, Esq., Graduate.

Elliott Memorial Prize

The Elliott Memorial Prize, which is awarded twice a year to R.A.F. Apprentices at Halton, has been awarded to 579641 Aircraft Apprentice F. L. Langley. An August, 1943, entry, he obtained the highest number of marks in the General Studies Examination. The prize, value two and a half guineas, was awarded to him at the Passing-Out Prize Giving ceremony at Halton on the 31st July, 1946.

Busk Studentship in Aeronautics

The Busk Studentship for the year 1946-7 has been awarded by the Trustees to Richard Peter Boswell, of Hawker Aircraft, Ltd.

The Studentship was founded in memory of Edward Teshmaker Busk, who was killed in 1914 while flying an experimental aeroplane.

There is also the Edward Busk Memorial Prize of the Royal Aeronautical Society which is offered annually for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes, including seaplanes.

Members Going Abroad

The Society would appreciate it if members going abroad would notify the Secretary so that he could put them in touch with local branches of the Society in the countries they may be visiting. Overseas Branches are anxious to meet and extend a welcome to members coming from Great Britain.

Branches of the Society

Fellows, Associate Fellows and members in other grades of the Society are reminded that the Society has many Branches throughout the World. If members are resident in Great Britain no additional subscription is required in respect of Branch Membership.

Each Branch organises lectures, meetings, and visits in its area, and in many cases Branch Libraries are available.

All Members are invited to get in touch with their local Branch Secretary (a list was published in the July Journal) to obtain fuller details.

Meetings at the Headquarters of the Society

During July the following meetings of other organisations were held at 4, Hamilton Place, the headquarters of the Society:—

Aeronautical Research Committee (on various occasions).

Air League of the British Empire, Annual General Meeting.

College of Aeronautics, Cocktail Party and meeting with members of the Empire Press and the British Press.

Guild of Air Pilots and Air Navigators.

Naval Appointments Board of the Admiralty. (In Committee Room 1 for two weeks).

History of the Society

An illustrated history of the Society has been prepared covering the first eighty years 1866-1946. The history contains many remarkable references to and extracts from the early

proceedings of the Society, showing how its members played an astonishing part in the development of flight, from initiating the earliest wind tunnel experiments in the world and the first discussion, nearly sixty years before the event, on jet propelled aircraft, to the most modern developments.

It is hoped that every member will acquire a copy of this history, of which only a limited edition has been printed. It can be obtained from the offices of the Society price 5/3 post paid.

Changes of Address

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

German Long-Range Rocket Development

Attention to a misprint in Mr. Perring's paper, "German Long-Range Rocket Development," in both the Advance Proof and the July Journal, has been drawn by Mr. A. V. Cleaver, Associate. In the expressions given for both velocity and specific impulse the term $\left(1-\frac{p_x}{p_o}\right)\frac{\gamma-1}{\gamma}$ should read $\left\{1-\left(\frac{p_x}{p_o}\right)\frac{\gamma-1}{\gamma}\right\}$ and the expression, on page 495,

$$\frac{p}{p_o}=\left(\frac{T}{T_o}\right)\frac{\gamma-1}{\gamma} \text{ should read } \frac{p}{p_o}=\left(\frac{T}{T_o}\right)\frac{\gamma}{\gamma-1}$$

The Journal

The Editor will always be glad to receive any suggestions for improving the Journal, either in the way of make-up or the papers and general contents of the Journal.

Graduates' and Students' Section

VISITS:—

August 17th. A visit has been arranged to the works of Short Bros. (Rochester and Bedford), Ltd., at Rochester on Saturday, 17th August. Applications to attend should be sent to the Hon. Secretary, J. G. Roxburgh, 62, Fitzjohn Avenue, N.W.3, and must be received at least one week before the date of the visit.

September 25th. A visit has been arranged to the Aerodynamics Section of the National Physical Laboratory, Teddington, on Saturday, 28th September, at 2.30 p.m. Applications to attend this visit should be sent to the Hon. Secretary, J. G. Roxburgh, 62, Fitzjohn Avenue, London, N.W.3, and must be received not later than a week before the date of the visit.

Branches

HATFIELD BRANCH

August 23rd and *24th.* A visit has been arranged to Thomas Firth and John Brown, Ltd., at Sheffield on Friday and Saturday, 23rd and 24th August, 1946.

August 23rd. A visit has also been arranged on the 23rd August to the Northern Aluminium Co., Ltd., at Banbury.

Election of Members

Fellows

John Cowan Stevenson (from Associate Fellow).

Associate Fellows

Frank William Bennett, George Robert Brailsford (from Graduate), Roy William Brown (from Graduate), Peter Allan Coles (from student), Dewi Manuel Davies (from Graduate), Eric Oswald Draper (from Graduate), Robert George Hoare, Brian Ruckman Hutchinson (from Graduate), Yung-Shih Lung, Brian Douglas Friend Maclaren, James Dorrien Richards, Ronald Smelt, Philip Burrows Smith, Alec Julian Tyndale-Biscoe, Reginald Thomas Vaughan-Johnson, John Miles Warner (from Student), Kenneth Edmund Westover (ex-Student), Frederick Robert Willis, John Antony Joseph Randal Lowndes Withnell (from Student).

Associates

Keith Sylvester Alderton, Vernon Berry, Wilfred Richard Billingsley, Arthur Herbert Thomas Brazier, Arthur Ronald Butler (from Graduate), Conrad Sandford Carpenter, Thomas George Cribb, Derrick Orme Dooyewaard (from Student), Kenneth James Dowell, Vivian Woodland Erlebach (from Student), Haydn Iestyn Evans, Thomas Reginald Floate (from Student), Cedric Kenneth Giles, John Brodie Goodsir (from Graduate), Yuan-Tso Han, Basil Joseph Herington, Ivor William Jones (from Companion), Wilfred Kenyon, John Stephen Raymond Jones, Thomas Albert Lloyd, Neville Lloyd Lupton, Ronald William Ernest Martin, Robert John Millson (from Student), Stanley Thomas Moore, Eugene Pessen, Palemon Plant, Frank Wilson Quiggin, John Edward Radcliffe, Vivian Farrar Smith, Albert Hilton Sturgess, Wilfred Kenneth Tedham (ex-Student), Leonard Thornhill, George Stewart Webley, William Welton.

Graduates

Roderick James Rogers Armstrong, Jasper Stephen Butcher (from Student), Henry Cohen, James Alexander Gwilym Diack (from Student), Royston Charles Lunn, James Cedric Morrall, John Morris, Alan Henry Robinson (from Student), Maurice Rothman, Bhagwan Tuljaram Shahani, Arthur William Syme, John Michael Lawson Thomas, John Walter Charles Whenmouth (from Student).

Students

Peter John Baillie, M. S. Balasubramanian, John Rutherford Barrie, Franck John Maurice Bonneres, Jesse Herbert Booth, Geoffrey Cooper, Geoffrey Percival Dollimore, Frederick Bryan Monge, Bernard Patrick Nann, Conyers Rutter, William Stewart Thompson.

Companions

Peter George Cooksley, Percy Llewellyn Hunting, George Thomas Shelswell.

Acknowledgments

The Council acknowledge with grateful thanks the following gifts:—

First Day Air Mail Covers: From K.L.M., Royal Dutch Air Lines.

Books: From Griffith Brewer, Esq., Hon.F.R.Ae.S., and B. J. Hurren, Esq.

Journals: From Aircraft Materials, Ltd., Captain J. F. Arnold, A.F.R.Ae.S., W. J. Halland, Esq., A.F.R.Ae.S., and Wing Commander R. Hollingsworth, A.F.R.Ae.S.

Additions to Library

A.a.319.—On the Transmission of Sound Waves through a Shock Wave. J. M. Burgers. Koninklijke Nederlandische Akademie van Wetenschappen. North Holland Publishing Co., Amsterdam. 1946. Y.i.

A.a.320.—Diagrams of a critical flutter speed for wings of a certain standard type. A. I. van der Vooren and J. H. Greidanus, National Aeronautical Research Institute, Amsterdam. 1946. Y.i.

B.a.363.—Swordfish Saga. B. J. Hurren. Fairey Aviation Co. n.d.

E.b.118. Experimental Stress Analysis, proceedings of the Society for—Vol. III. No. 2. C. Lipson and W. M. Murray (ed.) Addison-Wesley Press, N.Y. 1946.

EE.c.81.—Primer of the Internal Combustion Engine. H. E. Wimperis. Constable. 1944.

G.e.A.101.—Forming of Aluminium Alloys by the Rubber Die Process. Aluminium Development Association. 1945.

G.e.J.27.—Metallography of Magnesium and its Alloys. Walter Bulian and Eberhard Fahrenhorst. F. A. Hughes. 1944.

L.a.55.—Aircraft Engineer's "C" License. G. W. Williamson. Newnes. 1946.

L.d.108.—Aerial Navigation. H. E. Benham. Wiley, N.Y. 1945.

M.a.30.—Batteries into Battle. Chloride Electrical Storage Co. 1946. Y.18.i.

R.c.287.—The Aero Manual. 1909, 1910. Temple Press. 1909.

R.c.288.—The Aero Manual. 1910. Temple Press. 1910.

S.e.120.—Bomber Command. Air Ministry. H.M.S.O. 1941.

S.e.121.—Wings of Warfare. Geoffrey D. M. Block. Hutchinson. 1945.

T.a.115.—Fifty Years of Flying. Griffith Brewer. Air League of the British Empire. 1946.

U.i.26.—Transactions—American Society of Mechanical Engineers. 1946.

Z.a.21. Bradshaw's British and International Air Guide. May, 1946.

J. LAURENCE PRITCHARD, *Secretary.*

Made and Printed in Great Britain by the Lewes Press, Lewes, Sussex.

TECHNOLOGY DEPT.

THE ROYAL AERONAUTICAL SOCIETY

4, HAMILTON PLACE, PICCADILLY, LONDON, W.1

SEPTEMBER NOTICES 1946

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

Contents of September Journal

The Silencing of Aircraft, by N. Fleming, M.A.

Aeronautics and the Metallurgist, by Professor L. Aitchison, D.Met., B.Sc., F.R.I.C., F.R.Ae.S.

Strength of Screw Threads of Whitworth Form, by J. V. Inglesby, M.A., D.I.C., F.R.Ae.S.

British Empire Lecture

The second British Commonwealth and Empire Lecture will be given by Sir Henry Self, K.C.M.G., K.B.E., C.B., Permanent Secretary to the Ministry of Civil Aviation, at 6 p.m. on Wednesday 25th September 1946 at the Institution of Civil Engineers, Great George Street, S.W.1. The subject of the lecture is " The Status of Civil Aviation in 1946." (*Please note alteration of date.*)

Garden Party

The Society will hold a Garden Party at Radlett Aerodrome on Sunday 15th September 1946.

It has been possible to make the necessary arrangements for the Garden Party by the kindness of the Society of British Aircraft Constructors and the President, Sir Frederick Handley Page.

The Society of British Aircraft Constructors are holding their Flying Display and Exhibition at the Handley Page Aerodrome, Radlett, Hertfordshire, and they and the aircraft companies concerned have generously agreed to keep the Display and Exhibition in being especially for members of the Society and their friends.

Two hundred British companies, manufacturers of aircraft, aero-engines, propellers, instruments, components and materials, will show their products. Modern types of commercial and combat aircraft will also be shown, as well as the latest power plants, both piston and gas turbine units. There will be a flying display, which will include some of the latest British civil and military aircraft.

The President of the Society, Sir Frederick Handley Page, has kindly consented to make the aerodrome available to the Society's members and their guests for the day.

The Display will begin at 2.30 p.m. and end at 7.30 p.m.; tea will be served to members and their guests. Admission will be by ticket only, obtainable only through a member of the Society. A car park will be available for those who come by road. Cameras will be allowed but dogs will not be admitted.

The number of tickets available will be limited and application should be made as early

as possible to avoid disappointment. Each member will be allowed a maximum of four tickets in all, one for himself and three for guests. The price of the tickets is 7/6 each.

Will members applying for tickets please enclose remittance and write their names in block letters and *give their membership grade*, as otherwise there may be a delay in issuing tickets to them.

The Library

The Library will be closed on Wednesday 11th September and Thursday 12th September.

Helicopter Prize

The Helicopter Association of Great Britain are offering an annual prize of £25 for a paper of a technical nature on some aspect of Rotary wing flight.

The general conditions are that the competition is open to British subjects under the age of 35 years on 31st December and that the entries for 1946 must be received by 31st December 1946.

The subject for the 1946 competition is " The Technical and Economic Problems of Rotary-wing as opposed to Fixed-wing Aircraft, and their application to the future of Civil Aviation."

Any inquiries should be made to the Helicopter Association of Great Britain, Finsbury Circus House, Blomfield Street, London, E.C.2.

Birthday Honours

M.B.E. (Civil Division)—B. Kaiser, Esq., A.M.I.Mech.E., M.I.Ae.Sc., Associate Fellow.

Sixth International Congress of Applied Mechanics

The Sixth International Congress of Applied Mechanics will be held in Paris from September 22 to 29 1946.

Members will be able to obtain any information they need from the Secretariat for the Congress, which will be open from the 15th September at the Sorbonne, rue des Ecoles (nearest Underground station " Odéon " or " Gare du Luxembourg ").

All arrangements for the journey must be made by the members themselves.

Members are recommended to take with them their week's ration of tea, sugar, soap and powdered or condensed milk. A small tin of coffee would also be useful. Members should also bring their own towels.

To meet the request of a number of members, six symposia have been added to the programme already drawn up of the Congress (General lectures and meetings of 4 sections); each of these symposia will be held on a different day. They are:—

(1) Advances in the study of the strength of materials (distribution of stresses in joints, buckling, etc.); chairman, Mr. Caquet and N. Hoff.

(2) High-speed Flow; chairman, Prof. Von Karman.

(3) Aerofoil theory and related matters; chairman, Prof. S. Goldstein and J. Pérès.

(4) Turbulence; chairman, Prof. H. Dryden and Kampe de Feriet.

(5) Jet Propulsion and Combustion; chairman, Mr. H. Constant and Prof. Roy.

(6) Approximate methods of computation, numerical and experimental; chairman, Prof. R. V. Southwell.

The only languages employed at the Congress will be French and English.

Fuel Economy Conference

By invitation of the Netherlands National Committee, the Fuel Economy Conference of the World Power Conference will be held at The Hague, Holland, from 2nd - 10th September 1947. Further particulars may be obtained from: British National Committee, World Power Conference. 36 Kingsway, London, W.C.2.

Associate Fellowship Examinations

Members are reminded that the new syllabus for the Associate Fellowship examinations will come into force on 1st January 1948.

Applications for the next Associate Fellowship examinations, to be held in December 1946, must be received by the Secretary not later than 30th September. Members studying for these examinations under the current syllabus will be examined under that syllabus.

History of the Society

An illustrated history of the Society has been prepared covering the first eighty years 1866-1946. The history contains many remarkable references to and extracts from the early proceedings of the Society, showing how its members played an astonishing part in the development of flight, from initiating the earliest wind tunnel experiments in the world and the first discussion, nearly sixty years before the event, on jet propelled aircraft, to the most modern developments.

It is hoped that every member will acquire a copy of this history, of which only a limited edition has been printed. It can be obtained from the offices of the Society price 5/3 post paid.

Meetings at the Headquarters of the Society

During August the Aeronautical Research Committee held a number of meetings at 4 Hamilton Place and the air charter companies, which have formed an association of charter companies, held two meetings.

Graduates and Students Section

3rd October Thursday. Discussion on the Design of Wings. Part I.

The discussion will be introduced by three 15 minute papers on the following aspects of wing design:—

" Aerodynamic Design of Wings," by Mr. E. J. N. Archbold, B.Sc., Grad.R.Ae.S.

" Wing Stiffness," by Mr. R. L. E. Toms, Grad.R.Ae.S.

" Wing Weight," by Mr. J. Spillman, Grad.R.Ae.S.

15th October Tuesday. Discussion on the Design of Wings. Part II.

The discussion will be introduced by two 15 minute papers on:—

" Wing Testing," by Mr. K. R. Obee, Grad.R.Ae.S.

" Swept Back Wings," by Mr. J. W. F. Housego, Grad.R.Ae.S.

30th October Wednesday.

A lecture will be given on " The Application of the Wind Tunnel to Aircraft Design," by Mr. E. J. Richards. Mr. Richards is in charge of the Aerodynamics Department at Vickers-Armstrongs, Weybridge.

All the above meetings will be held in the Library of the Society, 4 Hamilton Place, W.1, at 7.30 p.m.

Associate Fellowship Examination Results

The following were successful in the Associate Fellowship Examination held in May 1946.

J. M. Allwright, Applied Mathematics, Theory of Internal Combustion Engines; E. H. Amor, Aircraft Materials; J. A. Anderson, Applied Mathematics; G. E. Archdale, Pure Mathematics (1st Place); C. R. Baines, Theory of Internal Combustion Engines (1st Place); J. C. Barrett, Pure Mathematics; G. B. Bhide, Pure Mathematics, Aircraft Materials (1st Place); G. W. Bleasdale, Applied Mathematics (1st Place); D. R. Blundell, Aerodynamics; G. Boyce, Applied Mathematics; P. C. G. Brazier, Strength of Aeronautical Materials and Structures; R. P. Castle, Strength of Aeronautical Materials and Structures; D. C. Chappel, Pure Mathematics; J. R. Combley, Pure Mathematics; P. R. Dymond, Pure Mathematics; P. Ebershardt, Design (Aircraft); G. D. Evans, Applied Mathematics, Aircraft Instruments (1st Place); J. R. C. Fearon, Pure Mathematics, Theory of Machines; A. H. Fernando, Applied Mathematics; G. Gallia, Theory of Machines; P. L. E. Gallimore, Pure Mathematics; E. B. Garlah-Watkins, Aircraft Instruments; M. A. Glasspole, Pure Mathematics; E. M. Harris, Pure Mathematics, Strength of Aeronautical Materials and Structures, Aerodynamics; D. S. Haldipur, Applied Mathematics; N. T. W. Harper, Applied Mathematics; P. A. Hatswell, Pure Mathematics; P. A. Hearne, Aerodynamics; E. Hobart, Applied Mathematics, Aerodynamics, Theory of Machines (1st Place); J. A. Howard, Design (Aero-Engines); K. T. Jackson, Theory of Internal Combustion Engines; A. James, Applied Mathematics, Aerodynamics, Design (Aircraft); R. Kendall, Theory of Machines; P. G. Kendrick, Navigation; G. G. Legg, Design (Aircraft); A. MacDonald, Aerodynamics, Design (Aero-Engines) (1st Place); G. McIntosh, Pure Mathematics; J. G. Mason, Pure Mathematics, Strength of Aeronautical Materials and Structures (1st Place), Aerodynamics (1st Place); D. J. Mead, Aerodynamics; O. R. B. Moorman, Strength of Aeronautical Materials and Structures, Design (Aircraft); R. May, Pure Mathematics; H. M. Nerriere, Applied Mathematics, Design (Aero-Engines); P. I. D. O'Brien, Pure Mathematics; A. E. Polden, Theory of Internal Combustion Engines; F. B. Perry, Pure Mathematics, Design (Aircraft); J. L. Raynes, Applied Mathematics; H. Rewitch, Theory of Internal Combustion Engines; N. Ring, Applied Mathematics, Strength of Aeronautical Materials and Structures, Design (Aircraft) (1st Place); F. H. Robertson, Design (Aircraft); G. L. Ronson, Theory of Machines; D. K. Saunders, Pure Mathematics; E. Slap, Applied Mathematics; B. L. Sowry, Applied Mathematics, Design (Aircraft); P. E. A. Stevenson, Theory of Internal Combustion Engines; R. S. Sowter, Applied Mathematics; P. D. Walters, Pure Mathematics; J. Watkins, Theory of Internal Combustion Engines; J. K. Yates, Air Transport; L. Young, Pure Mathematics, Theory of Internal Combustion Engines, Theory of Machines.

Election of Members

Associate Fellows

Johannes Martinus Burgers; William Leigh Houlbrook, Fidia James Piattelli, Harold Peter Stapleford (from Graduate), Herbert Ronald Watson.

Associates

Egbert Giles, Thomas Hunt, Kelipakam Lakshmi Kantham, Benjamin Kaye, Joseph Liddell, William Richard Morris, Richard Charles Rowe, Edward Simpson, Joseph Wilkinson.

Graduates

Ronald Terence Bunting, David Mostyn Davies, Frederick Ronald Green, Charles Henry Jenno (from Student), Reginald John Arthur Jones, Tung-Chi Lin.

Vacancies at Farnborough

The Civil Service Commissioners invite applications for the posts of Superintendent at the Royal Aircraft Establishment, South Farnborough, Hants, under the Ministry of Supply.

1. *Superintendent of the Chemistry Division.*

The successful candidate will be expected to supervise research and development on non-metallic materials used in aircraft and associated aircraft equipment.

Applicants should have the following qualifications:—

(a) An established reputation for research in some branch of Chemistry, preferably with a slight bias towards its physical aspects.

(b) A general acquaintance with the Universities and other United Kingdom Government or Industrial Research Laboratories or Associations.

(c) D.Sc. or F.R.I.C.

(d) Experience of the organisation and administration of research.

Some experience of Departmental procedure is preferable but not essential.

2. *Superintendent of a Division dealing with Flutter, Aero-Elasticity and General Airframe Vibration.*

The successful candidate will be expected to supervise research work in the subjects mentioned above and give guidance in the application of new principles of existing aircraft and to new designs.

Applicants should have the following qualifications:—

(a) An Honours degree in Engineering, Mathematics or Physics.

(b) Research experience supported by original scientific reports and patents.

(c) Experience in flutter work.

A general knowledge of aerodynamics and aircraft design is also desirable.

3. *Superintendent of the Metallurgy Division.*

The successful candidate will be expected to supervise research and development of metals used in aircraft and associated aircraft equipment.

Applicants should have the following qualifications:—

(a) An established reputation for research in aircraft metals with the qualification D.Sc or, alternatively, an Honours degree in Physics and specialist experience in research on metals.

(b) A general acquaintance with the Universities and other United Kingdom Government or Industrial Research Laboratories or Associations.

(c) Experience of the organisation and administration of research.

Some experience of Departmental procedure is preferable but not essential.

These posts carry the rank of Senior Principal Scientific Officer, for which the London salary scale is £1,200 × £50—£1,400. This scale is subject to deduction in the case of appointments outside London. The deduction varies according to the location and salary, and for the posts advertised is £100 throughout the scale.

The salary will be increased by a consolidated addition (in place of War Bonus) which, on this scale, is £120.

The posts carry Superannuation benefits under the Federated System for Universities.

Candidates must be of British nationality and not more than 50 years of age. They must possess the stipulated qualifications and experience.

Further details, together with application forms, may be obtained from the Civil Service Commission, 6 Burlington Gardens, London, W.1, quoting No. 1611, with whom completed applications must be lodged by 30th September 1946.

Acknowledgments

The Council acknowledge with grateful thanks a copy of the paper " Stability Problems with Swept Wings," by Hartley A. Soulé (delivered to the Society of Automotive Engineers in the United States) from Group Captain C. Clarkson.

Additions to the Library

M.a.31.—Accumulator Charging, Maintenance and Repair. W. S. Ibbetson. Pitman, 1946.

N.a.86.—Relaxation Methods in Theoretical Physics. R. V. Southwell. Clarendon Press, 1946.

OO.120.—*Final Report of Operations Division. P.I.C.A.O. First Session.* 1946. *Montreal.*

OO.121.—*Final Report of Airworthiness Division. P.I.C.A.O. First Session.* 1946. *Montreal.*

Q.a.166.—*Recent Aeronautical Literature—selective subject index for* 1945. *Willard Kelso Dennis. Beech Aircraft Corporation, Wichita, Kansas.* 1946.

S.e.122—Pathfinders. Wing Commander B. Anderson. Jarrolds. 1946.

UF.3.—*Publications Scientifiques et Techniques du Ministère de l'Air. Nos.* 145-160, 162, 165, 168-193, 198-200.

UF.4.—*Bulletins des Services Techniques. Nos.* 92-105. *Notes Techniques. Nos.* 1-16, 23.

UE.2.—*Large Distortions of circular rings and straight rods. A van Wijngaarden. Reprint from the proceedings of the Koninklijke Nederlandsche Akademie van Wetenschappen. North Holland Publishing Co. Amsterdam.* 1946.

UG.14.—*Untersuchungen an Verdichtungsstossen und Greuzschiscten in Schnell bewegten Gasen. J. Ackeret, F. Feldmann, N. Rott. Mitteilungen aus dem Institut für Aerodynamik, Zurich. Leeman & Co., Zurich.* 1946.

V.2.13.—Transactions of the Chartered Institute of Patent Agents. Vol. LXII. 1943-44. E. J. Bloomfield (Ed.). 1946.

X.e.59.—Bristol Engineering Directory. 9th edn. 1946. Bristol Engineering Manufacturers Association. 1946.

J. LAURENCE PRITCHARD,
Secretary.

Made and Printed in Great Britain by the Lewes Press, Lewes, Sussex.

ENGINEERING DEPT.

THE ROYAL AERONAUTICAL SOCIETY

4, HAMILTON PLACE, PICCADILLY, LONDON, W.1

OCTOBER NOTICES 1946

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

Contents of October Journal

Second British Commonwealth and Empire Lecture—The Status of Civil Aviation in 1946, by Sir Henry Self, K.C.M.G., K.B.E., C.B.

Meteorology and High Altitude Aviation, by Professor G. M. B. Dobson, M.A., D.Sc., F.R.S., and Mr. A. W. Brewer.

Evaluation of Aeroplane Metals, by Professor J. Van den Broek, M.E.I.C.

The 1946 Garden Party Report.

Lanchester's 1894 Models

The Society has been presented by Mrs. Lanchester with Dr. Lanchester's original aircraft flying models with which he experimented in June, 1894. With these models Lanchester made flights up to 600 yards, lasting 27 seconds and the result, " was to confirm the author's views as to the possibility of securing automatic stability without the employment of any equilibrium mechanism or ' brain equivalent,' " to quote from his " Aerodonetics."

These models are of great historic interest. Designed before any man had flown, from them Lanchester built up his theory of flight in his two astonishing volumes "Aerodynamics" and "Aerodonetics," published in 1907 and 1908, which are enduring monuments to his genius.

Baden Powell Memorial Prize

The Major Baden Powell Memorial Prize, which is awarded to the candidate considered by the examiners to be the best entrant in the Society's Associate Fellowship examinations, has been awarded to Mr. J. G. Mason on the result of the May, 1946, examinations.

Helicopter Lectures

The following lectures will be given before the Helicopter Association of Great Britain:—

Saturday, 12th October, 1946, at 3 p.m.: A Historical Review of Helicopter Development, by Group Captain R. N. Liptrot, C.B.E.

Saturday, 9th November, 1946, at 2.45 p.m.: Helicopter Research and Development, by C. G. Pullin, M.I.A.E., A.F.R.Ae.S.

The lectures will be delivered in the Lecture Hall, Manson House, 26 Portland Place, W.1, and members who wish to attend can obtain tickets from the Secretary of the Association, Finsbury Circus House, Blomfield Street, E.C.2 (Tel.: London Wall 6356). Each paper will be followed by a short film.

Lecture Programme

The following are the forthcoming lectures for the Autumn Session, 1946. Members are admitted without tickets, but non-members must obtain tickets through a member.

The lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1 (by permission of the Council of the Institution), except that of 29th November. Tea will be served at 5.30 except where otherwise stated.

9th October—A Critical Review of German Research on High-Speed Air Flow, by Mr. R. Smelt, M.A., A.F.R.Ae.S.

23rd October—The Problems of Blind Landing, by Mr. H. C. Pritchard, B.A., A.F.R.Ae.S.

31st October—Aeroelastic Problems at High Speed, by Professor A. R. Collar, M.A., B.Sc., F.R.Ae.S.

14th November—DISCUSSION ON ENGINEERING PROBLEMS OF FUTURE AIRCRAFT.

A full-day discussion will be held in the Lecture Hall of the Institution of Civil Engineers, at which the following papers will be read:—

MORNING SESSION

11 a.m. Power Installations, by Mr. F. M. Owner, F.R.Ae.S.
12 noon. Tailless Aircraft, by Mr. G. H. Lee, A.F.R.Ae.S.
1-2.30 p.m. Luncheon interval. Members and visitors should make their own arrangements for lunch.

AFTERNOON SESSION

2.30 p.m. Flying-Boats, by Mr. C. P. T. Lipscomb, F.R.Ae.S.
3.30 p.m. Large Aircraft, by Mr. A. E. Russell, F.R.Ae.S.
4.30-5 p.m. Tea interval (tea provided).

EVENING SESSION

5-6.30 p.m. General discussion and summing-up by the chairman.

29th November—Joint meeting with the Institution of Mechanical Engineers. Aircraft Propulsion, by Major F. M. Green and Mr. J. E. Wallington.

This meeting will be held in the lecture hall of the Institution of Mechanical Engineers, Storey's Gate, St. James's Park, S.W.1, at 5.30 *p.m.*

5th December—Protection of Aircraft Against Ice, by Mr. J. K. Hardy.

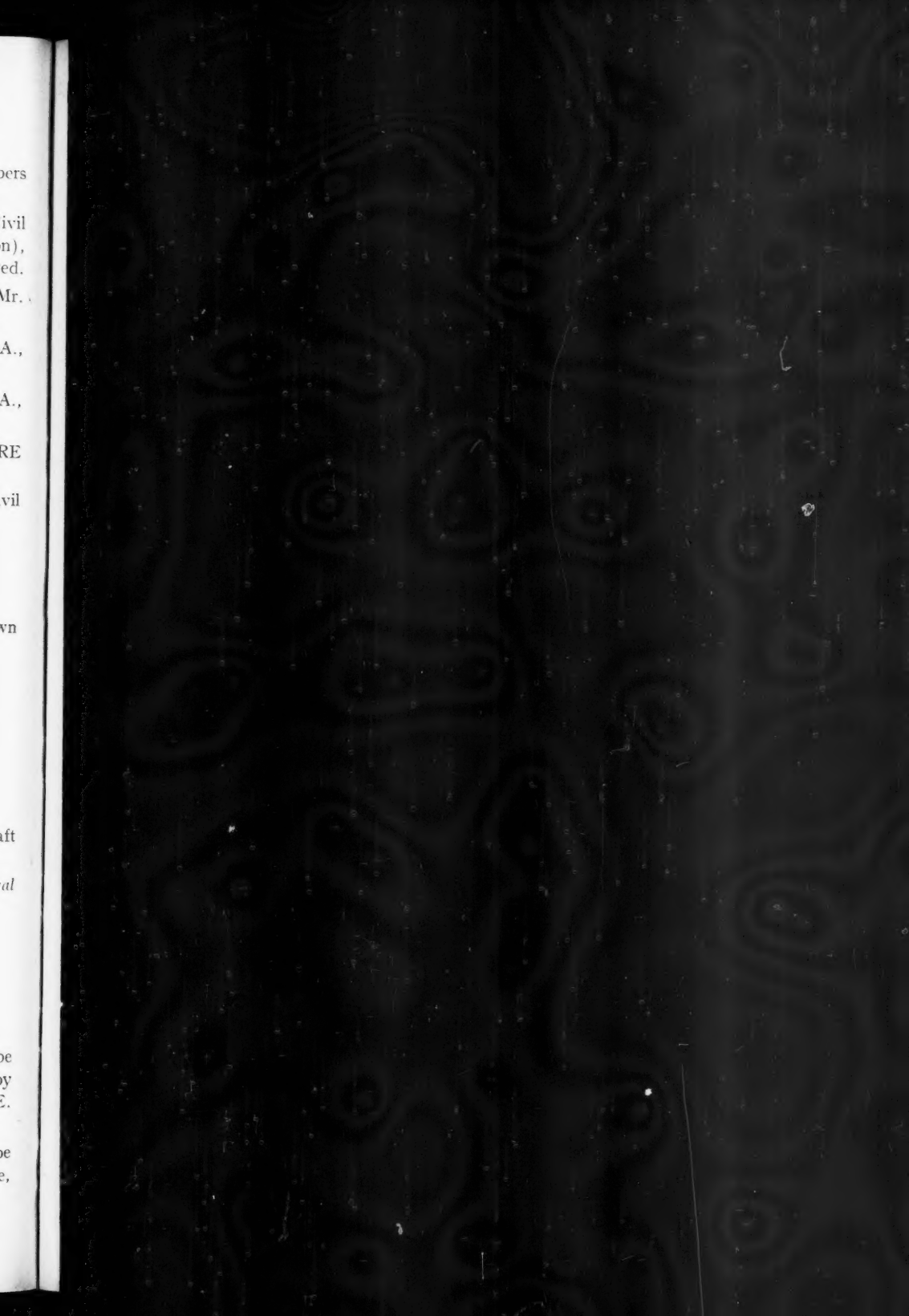
11th December—Photolofting, by Mr. S. P. Woodley.

19th December—The Evolution of the Spitfire, by Mr. J. Smith, C.B.E., F.R.Ae.S.

Graduates' and Students' Section

3rd October—DISCUSSION ON THE DESIGN OF WINGS, PART I. The discussion will be introduced by three 15 minute papers on: Aerodynamic Design of Wings, by Mr. E. J. N. Archbold, B.Sc., Grad.R.Ae.S.; Wing Stiffeners, by Mr. R. L. E. Toms, Grad.R.Ae.S.; Wing Weight, by Mr. J. Spillman, Grad.R.Ae.S.

15th October—DISCUSSION ON THE DESIGN OF WINGS, PART II. The discussion will be introduced by two 15 minute papers on: Wing Testing, by Mr. K. R. Obee, Grad.R.Ae.S.; Swept-Back Wings, by Mr. J. W. F. Housego, Grad.R.Ae.S.



30th October—A lecture will be given on the Application of the Wind Tunnel to Aircraft Design, by Mr. E. J. Richards, A.F.R.Ae.S. Mr. Richards is in charge of the Aerodynamics Department at Vickers-Armstrongs Ltd., Weybridge.

9th November—Members of the Graduates' and Students' Section are invited to a meeting of the Helicopter Association to be held at 2.45 p.m. in the Lecture Hall, Manson House, 26 Portland Place, W.1, at which a lecture on Helicopter Research and Development will be given by C. G. Pullin, Esq., M.I.A.E., A.F.R.Ae.S.

21st November—A lecture will be given on Structures in Aircraft Design, by Mr. R. H. Sandifer, F.R.Ae.S., who is in charge of the Stress Office at Messrs. Handley Page Ltd.

All meetings, except where stated otherwise, will be held in the Library of the Society, 4 Hamilton Place, W.1, at 7.30 p.m.

Visit.—A visit has been arranged on Saturday, 9th November, to the works of Percival Aircraft Ltd., and D. Napier and Son Ltd., both at Luton, Bedfordshire. Applications to attend the visit should be sent to the Hon. Secretary, J. G. Roxburgh, 62 Fitzjohns Avenue, London, N.W.3, not later than one week before the date of the visit.

Branch Lectures and Notices

BELFAST BRANCH

22nd October—Flying Experiences, by Capt. R. C. Parker, B.O.A.C.

12th November—Future Development of Aircraft for Civil Aviation, by Mr. N. A. White.

10th December—Wind Tunnels, by Mr. J. A. Kirk.

7th January, 1947—Gliding, by Professor Hill.

24th January, 1947—Smoking concert.

11th February, 1947—Electrics in Aircraft, by Mr. Woodford.

11th March, 1947—Gas Turbines and Jets, by Mr. J. Hodge.

All lectures will be held in the Central Hall, Belfast College of Technology.

BIRMINGHAM BRANCH

10th October—Fluid Springs, by Mr. R. H. Bound, F.R.Ae.S., at the Birmingham Chamber of Commerce.

22nd October—Annual General Meeting, followed by concert, at White Horse Hotel, Birmingham.

14th November—Some Problems of High-Speed Flight, by Dr. S. C. Redshaw, F.R.Ae.S., at Birmingham Chamber of Commerce.

19th December—Pneumatics for Aircraft and the Aircraft Industry, arranged by Hymatic Engineering Co. Ltd., at Birmingham Chamber of Commerce.

All meetings will begin at 7 p.m.

The second annual dinner and dance of the Birmingham Branch of the Society was held on September 7th, 1946, at Birmingham. Mr. A. C. Bound, Fellow of the Society and President of the Branch, was in the chair. Over 150 members and their friends attended, including Mr. J. Silverman, M.P., who proposed the toast of the Society, and the Deputy Lord Mayor of Birmingham, Alderman W. T. Wiggins-Davies. Professor L. Aitchison, a Fellow of the Society, who proposed the health of the guests, was replied to by the Deputy Lord Mayor of Birmingham.

DERBY BRANCH

7th October—Aerodynamical Aspects of High-Speed Flight, by Mr. D. W. Holder, D.I.C., B.Sc., of the National Physical Laboratory.

The meeting will be held at 6.15 p.m. in the Rolls-Royce Welfare Hall, Nightingale Road, Derby.

HATFIELD BRANCH

Visit.—A visit is to be made to the National Physical Laboratory, Teddington, on Saturday, 23rd November.

READING AND DISTRICT BRANCH

6th November—Film Show. Films are kindly being supplied by High Duty Alloys Ltd., showing various aspects of their work, and one of their representatives will be present to answer questions. The film will be given in the Upper Canteen at Miles Aircraft, Woodley; tea will be served from 5.30 p.m., and the film will begin promptly at 6 p.m.

4th December—Annual General Meeting. Members will be circularised individually with agenda at a later date.

4th January, 1947—Preliminary notice, Dinner dance.

Evening Classes: At the request of the Branch, the Reading Education Committee has arranged a course of evening classes at the University; initially the course will cover all aspects of aircraft design. The first course will start in the Autumn, 1946, and is not restricted to Branch members, but any of the latter who are interested can obtain details from the Branch Secretary.

SOUTHAMPTON BRANCH

16th October—Notes for Future Reference, by H. Roxbee Cox, Ph.D., D.I.C., F.R.Ae.S.

13th November—Air Transport Operation, by E. Brook Williams, Superintendent of Navigation, B.O.A.C.

11th December—Naval Aircraft, by A. N. Clifton, M.B.E., B.Sc., F.R.Ae.S.

8th January, 1947—Elementary Metallurgy of Aircraft Materials, by A. Black, M.I.M.

29th January, 1947—Installation of Radio Equipment in Aircraft, by W. T. Davies, A.M.I.E.E.

19th February, 1947—Problems in Fighter Design, by R. L. Lickley, B.Sc., D.I.C., F.R.Ae.S.

***19th March, 1947**—High-Speed Flight, by Mr. E. Greenwood, O.B.E., and Mr. R. Smelt, M.A., A.F.R.Ae.S.

***16th April, 1947**—By E. F. Relf, C.B.E., F.R.S., F.R.Ae.S.

* Not yet confirmed.

All lectures will be held at 7 p.m. in the Physics Lecture Theatre, University College, Southampton.

Election of Members

The following members were elected recently:—

Associate Fellows

Geoffrey Mungo Buxton, William Rede Hawthorne.

Associates

Maurice Andrew Birrell, Wilfred Edward Clark, Herbert Francis Davis.

Graduate

Donald Albert Jobson.

Acknowledgments

The Council wish to acknowledge with grateful thanks the gift of eight films and more than 600 slides from the Royal Observer Corps; and a copy of "Our First Airways," by Grahame White and Harry Harper, from P. M. Travers-Clarke, Esq., Associate.

Additions to the Library

B.e.47.—Model Aircraft Handbook. William Winter. Harrap. 1946.

D.e.36.—Air Transport. E. D. Weiss. Art & Educational Publishers. 1946.

D.f.45.—British Civil Airworthiness Requirements. Air Registration Board.

EE.c.82.—Aviation Mechanics Engine Manual. John W. Vale. McGraw Hill. 1946.

EE.h.20.—Elementary Gas Turbines and Jet Propulsion. J. G. Keenan. Oxford University Press. 1946.

EE.h.21. The Modern Gas Turbine. R. Tom Sawyer. Pitman. 1946.

EE.h.22.—Gas Turbines and Jet Propulsion for Aircraft. Geoffrey Smith. Flight. 1946.

N.a.86—Relaxation Methods in Theoretical Physics. R. V. Southwell. Oxford University Press. 1946.

R.f.115.—Balloon to Bomber. W. F. Burbridge. Crowther. 1946.

S.d.94.—I Hold My Aim. Group Captain C. H. Keith. Allen & Unwin. 1946.

S.e.123.—Bombs over Burma. W. G. Burchett. Cheshire. Melbourne. 1944.

S.e.124.—Forgotten Skies. Wing Comander W. W. Russell. Hutchinson. 1946.

T.b.99.—My Flying Scrapbook. Major C. C. Turner. Sampson Low. 1946.

UE.2.—*Some Problems of the Motion of Interstellar Gas Clouds. J. M. Burgers. Koninklike Nederlandsche Akademie van Wetenschappen.* 1946.

V.5 50.—Institution of Mechanical Engineers. Brief Subject and Author Index of papers in the Proceedings 1847-1945, and in the Journal. March 1939-March 1946. Institution of Mechanical Engineers. 1946.

W.b.17 16.—The Nickel Bulletin. Volume 16. 1943. Mond Nickel Company. 1944.

X.c.G.6.—Manual of German Air Force Terminology. German-English revised edition. Air Ministry A.I.12.

Combined Intelligence Objectives Sub-Committee:

Item No. 1. File No. I-1
Item No. 3 and 17. File No. XXXII-56.
Item No. 4. File No. XXXI-59.
Item No. 5. File No. XXXI-5.
Item No. 5. File No. XXIII-14.
Item No. 5, 26. File No. XI-6, XII-9, and XIV-4.
Item No. 21. File No. XXXIII-32.
Item No. 25. File No. IV-7 and V-16.
Item No. 30. File No. XXXII-68.

British Intelligence Objectives Sub-Committee:

Final Report No. 639. Item No. 30.
Final Report No. 598. Item No. 30.
Final Report No. 589. Item No. 31.
Final Report No. 585. Item No. 27.
Final Report No. 564. Item No. 1, 9, 29.
Final Report No. 557. Item No. 1, 7, 22, 27, 31.
Final Report No. 556. Item No. 4.
Final Report No. 500. Item No. 31.
Final Report No. 499. Item No. 18, 19, 26.
Final Report No. 67.
Final Report No. 176.
Final Report No. 100.
Final Report No. 225.
Final Report No. 293.
Final Report No. 423.
Final Report No. 602.
Final Report No. 801.
Final Report No. 11.

Ministry of Supply:

German Wartime Research in Physics.

J. LAURENCE PRITCHARD,
Secretary.

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TECHNOLOGY DEPT.

THE ROYAL AERONAUTICAL SOCIETY

4, HAMILTON PLACE, PICCADILLY, LONDON, W.1

NOVEMBER NOTICES 1946

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

Contents of November Journal

The Stresses in a Circular Fuselage, by W. J. Goodey, M.A., A.F.R.Ae.S.
The Case for the Tailless Aircraft, by G. H. Lee, A.F.R.Ae.S.
Notes on the Stalling Properties of Wings, by E. J. Richards, M.A., B.Sc., A.F.R.Ae.S.
Note on Ceramics for Gas Turbine Design, by S. W. G. Foster, A.F.R.Ae.S.

The Paris Aero Show

The Seventeenth Paris Aero Show will be held in the Grand Palais, Champs-Elysées, Paris, from the 15th November to the 1st December 1946 inclusive. During this time the Association Francaise des Ingénieurs et Techniciens de l'Aéronautique (A.F.I.T.A.), 6, Rue Cimarosa, Paris XVI^{e}, ARR^{t}, will be glad to give any assistance they can to members of the Society.

S.B.A.C. University Scholarships and Educational Grants

The following awards have been made:—

Mr. V. A. B. Rogers (nominated by Fairey Aviation Co. Ltd.); Scholarship to College of Aeronautics, Cranfield, Beds.

Mr. E. L. Goldsmith (nominated by Short Bros., Ltd.); Scholarship to Imperial College of Science and Technology, Kensington.

Mr. Keith G. Hodson; Educational Grant to De Havilland Aircraft Co. Ltd.

The Commonwealth Fund Fellowships

The Commonwealth Fund of New York has established for British subjects a number of Fellowships tenable in the United States.

Persons who come within one or other of the following categories are eligible:—

(1) For Ordinary Fellowships.—Candidates of British descent who are domiciled in the United Kingdom of Great Britain and Northern Ireland, and are degree graduates of recognised universities therein. Candidates must be over twenty-three and must not have attained the age of thirty-five on September 1st of the year of award. These Fellowships are also open to candidates of British descent from the British Dominions who have studied but not necessarily graduated at a university in the United Kingdom of Great Britain and Northern Ireland, and are degree graduates of a recognised university in a British Dominion or Colony.

(2) For Service Fellowships.—Candidates of British descent who hold appointments overseas under the British Government, or the Government of India, or the Government of a British Dominion, Colony, Protectorate or Mandated Territory.

(3) For Home Civil Service Fellowships.—Candidates holding appointments in the Home Civil Service.

Fellowships are not open to women.

The emolument attaching to each Fellowship, which is estimated at a minimum of approximately $3,500 for twelve months, is calculated to cover the full expenses of residence, study and travel in the United States during the year.

Generally, no limitation is imposed on the subject of study to be undertaken by the Fellow during the tenure of the Fellowship.

All applications must be submitted on the prescribed form and must reach the Secretary to the Committee, Richard H. Simpson, 35 Portman Square, London, W.1, by February 1st 1947 at latest.

Associate Fellowship Examinations December 1946

Associate Fellowship Examinations will be held on Monday and Tuesday, 30th and 31st December, 1946. All candidates will receive full particulars direct.

Meetings at the Headquarters of the Society

During recent weeks the following meetings of other organisations have been held at 4, Hamilton Place, the Headquarters of the Society:—

Aeronautical Research Committee (on various occasions).
British Air Charter Association.
International Union of Aviation Insurers.
Society of British Aircraft Constructors.
Guild of Air Pilots and Air Navigators.
Aircraft Recognition Society.

Vacancies at Farnborough

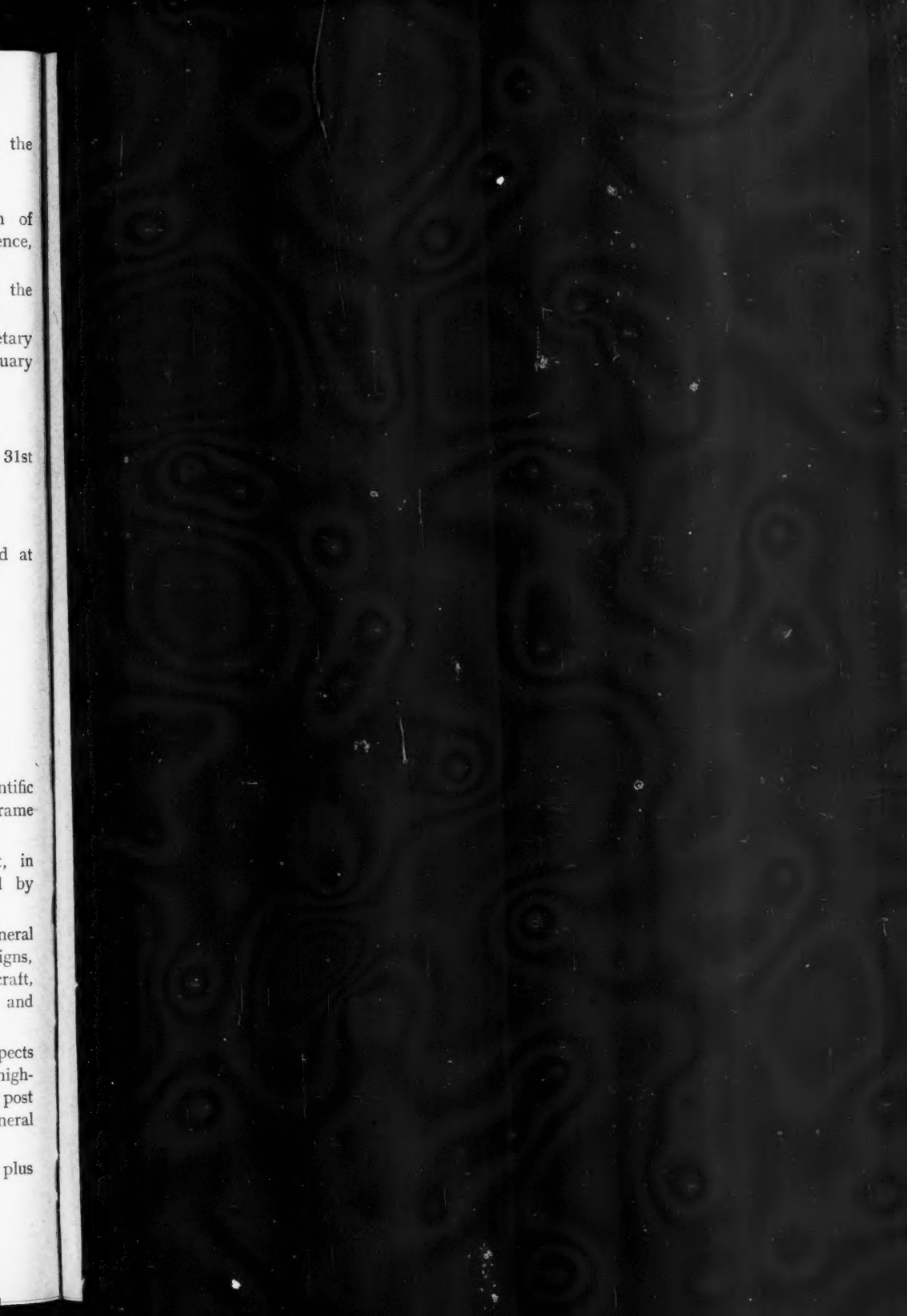
The Civil Service Commissioners invite applications for two posts of Principal Scientific Officer for Research and Development work on flutter, aeroelasticity and general airframe vibration at the Royal Aircraft Establishment, South Farnborough, Hants.

Candidates should have a first or second class honours degree, or the equivalent, in engineering, mathematics or science, and have either research experience supported by original papers, or aircraft design experience related to aeroelastic theory.

One Principal Scientific Officer is required to assist a Superintendent in the general supervision of flutter research and its application to existing aircraft and new designs, and especially to control and to guide experimental vibration work on actual aircraft, both in flight and on the ground. Some experience in flight testing, instrumentation and general engineering is necessary, and some knowledge of aerodynamics is desirable.

The second Principal Scientific Officer is required to specialise in the aerodynamic aspects of flutter. He must be prepared to give technical supervision in the design of a new high-speed flutter wind tunnel, and to take charge of its operation when completed. For this post extensive experience of wind tunnel testing, and knowledge of flutter theory and general aerodynamics, are essential.

The salary scale for these appointments is £750 plus 30—£1,020 (men) and £660 plus 30—£880 (women).



The salary will be increased by a consolidation addition (in place of War Bonus) which ranges from £90 at the minimum of the scale to £105 at the maximum for men and from £79 at the minimum of the scale to £84 at the maximum for women.

Candidates must be of British nationality and have been born on or before 1st August, 1915, and be under 50 years of age on 1st September, 1946. They must possess the stipulated qualifications and experience. The posts carry superannuation benefits under the Federated Superannuation System for Universities.

Forms of application are obtainable from the Civil Service Commission, 6, Burlington Gardens, London, W.1, quoting No. 1659, to whom completed applications must be returned not later than 18th November, 1946.

Vacancies at the National Gas Turbine Establishment

The Civil Service Commissioners invite applications for the following posts at the National Gas Turbine Establishment:—

1. For research on the processes of combustion.
2. For vibration investigations.

Candidates should have the following qualifications:—

1. They must have been born on or before 1st August, 1915, and be under 40 years of age on 1st September, 1946.
2. They should have first or second Class Honours degree in the appropriate subjects.

(*a*) *For Post* 1.

Physicist with experience either of combustion itself or of one of the related subjects such as gas analyses, aerodynamics, or thermodynamics.

(*b*) *For Post* 2.

Engineer with experience in the technique of vibration investigations.

The appointments will be graded in the Scientific Civil Service as Principal Scientific Officer.

The salary scales for the appointments are: £750 plus 30—1,020 (men) and £660 plus 30—880 (women).

The salary will be increased by a consolidation addition ranging from £90 at the minimum of the scale to £105 at the maximum for men and from £79 at the minimum of the scale to £84 at the maximum for women.

Candidates must be of British nationality and must possess the stipulated qualifications and experience. The posts are permanent with superannuation benefits under the Federated Superannuation System for Universities.

Forms of application are obtainable from the Civil Service Commission, 6, Burlington Gardens, London, W.1, quoting No. 1658, to whom completed applications must be returned not later than 18th November, 1946.

Temporary Appointments at Whetstone and Pyestock

Applications are invited for temporary appointments at the National Gas Turbine Establishment, for duty at Whetstone, Nr. Leicester, and Pyestock, Nr. Farnborough, Hants. Candidates must possess good scientific and/or technical qualifications and experience in one or more of the following classes of work:—

1. Aerodynamic investigations applied to gas turbines and compressors.
2. Combustion investigations at varying pressures and temperatures, including high altitude conditions.
3. Investigations of heat transfer.
4. Mechanical design of high speed machinery.
5. The application of electronic methods to problems of vibration.
6. The application of strain gauge methods to the examination of the stresses in rotating components.
7. Testing of engines and accessories, including flight test work.

Appointments will be made in the following grades; salaries, which will be determined by age, qualifications and experience, will be on the ranges shown:—

Senior Scientific Officer—£610 to £800.
Scientific Officer—£333 to £560.
Senior Experimental Officer—£660 to £840.
Experimental Officer—£452 to £610.
Assistant Experimental Officer—£218 to £398.

The ranges shown above are all inclusive of bonus.

So far as can be foreseen, the appointments will be for at least two years.

Applications, stating full details of qualifications and experience and the grade in which appointment is applied for, should be sent by 14th November, 1946, to the Secretary, Ministry of Supply (Est.5.(B)2), Room 828, Adelphi, London, W.C.2.

Changes of Address

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Lecture Programme

The following are the forthcoming lectures for the Autumn Session, 1946. Members are admitted without tickets, but non-members must obtain tickets through a member.

The lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1 (by permission of the Council of the Institution), except that of 29th November. Tea will be served at 5.30 except where otherwise stated.

14*th November*, 1946—DISCUSSION ON ENGINEERING PROBLEMS OF FUTURE AIRCRAFT.

A full-day discussion will be held in the Lecture Hall of the Institution of Civil Engineers, at which the following papers will be read:—

MORNING SESSION

11 a.m. Power Installations, by Mr. F. M. Owner, F.R.Ae.S.
12 noon. Tailless Aircraft, by Mr. G. H. Lee, A.F.R.Ae.S.
1-2.30 p.m. Luncheon interval. Members and visitors should make their own arrangements for lunch.

AFTERNOON SESSION

2.30 p.m. Flying-Boats, by Mr. C. P. T. Lipscomb, F.R.Ae.S.
3.30 p.m. Large Aircraft, by Mr. A. E. Russell, F.R.Ae.S.
4.30-5 p.m. Tea interval (tea provided).

EVENING SESSION

5-6.30 p.m. General discussion and summing-up by the chairman.

29th November, 1946—Joint meeting with the Institution of Mechanical Engineers. Aircraft Propulsion, by Major F. M. Green and Mr. J. E. Wallington.

*This meeting will be held in the lecture hall of the Institution of Mechanical Engineers, Storey's Gate, St. James's Park, S.W.*1, *at* 5.30 *p.m.*

5th December, 1946—Protection of Aircraft Against Ice, by Mr. J. K. Hardy.

11th December, 1946—Photolofting, by Mr. S. P. Woodley.

19th December, 1946—The Evolution of the Spitfire, by Mr. J. Smith, C.B.E., F.R.Ae.S.

Graduates' and Students' Section

9th November, 1946—Members of the Graduates' and Students' Section are invited to a meeting of the Helicopter Association to be held at 2.45 p.m. in the Lecture Hall, Manson House, 26 Portland Place, W.1, at which a lecture on Helicopter Research and Development will be given by C. G. Pullin, Esq., M.I.A.E., A.F.R.Ae.S.

21st November, 1946—A lecture will be given on Structures in Aircraft Design, by Mr. R. H. Sandifer, F.R.Ae.S., who is in charge of the Stress Office at Messrs. Handley Page Ltd.

All meetings, except where stated otherwise, will be held in the Library of the Society, 4 Hamilton Place, W.1, at 7.30 p.m.

Branch Lectures and Notices

BELFAST BRANCH

12th November, 1946—Future Development of Aircraft for Civil Aviation, by Mr. N. A. White.

10th December, 1946—Wind Tunnels, by Mr. J. A. Kirk.

7th January, 1947—Gliding, by Professor Hill.

24th January, 1947—Smoking concert.

11th February, 1947—Electrics in Aircraft, by Mr. Woodford.

11th March, 1947—Gas Turbines and Jets, by Mr. J. Hodge.

All lectures will be held in the Central Hall, Belfast College of Technology.

BIRMINGHAM BRANCH

14th November, 1946—Some Problems of High-Speed Flight, by Dr. S. C. Redshaw, F.R.Ae.S., at Birmingham Chamber of Commerce.

19th December, 1946—Pneumatics for Aircraft and the Aircraft Industry, arranged by Hymatic Engineering Co. Ltd., at Birmingham Chamber of Commerce.

All meetings will begin at 7 p.m.

BRISTOL BRANCH

5*th November*, 1946—The Basic Principles of Automatic Control, by Professor K. A. Hayes, O.B.E., D.Sc., M.I.E.E., Professor of Electrical Engineering, Military College of Science.

19*th November*, 1946—High Performance Gliding, by Mr. K. G. Wilkinson, B.Sc., D.I.C., British European Airways.

10*th December*, 1946—Some Notes for Future Reference, by Dr. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S.

(This lecture will be held at 6.30 p.m. in the large lecture hall of the Merchant Venturers Technical College and will be followed by a buffet supper.)

7*th January*, 1947—Brains Trust, with Captain J. Laurence Pritchard, Hon.F.R.Ae.S., as Question Master.

28*th January*, 1947—Large Aircraft, by A. E. Russell, Esq., B.Sc., F.R.Ae.S., Chief Engineer, Bristol Aeroplane Co. Ltd., Aircraft Division.

18*th February*, 1947—Radar—Its Uses and Possibilities in Civil Aviation, by F. R. Willis, Esq., B.Sc., A.M.I.E.E., A.F.R.Ae.S., Radio Development Section, B.O.A.C.

4*th March*, 1947 Some Aspects of Stability and Control, by Prof. A. R. Collar, M.A., B.Sc., F.R.Ae.S., Professor of Aeronautical Engineering, University of Bristol.

25*th March*, 1947—Competition for the best paper read by a Junior Member.

15*th April*, 1947—Annual general meeting and film show.

All meetings, except that of 10th December, 1946, will be held in the Conference Room, Filton House, Bristol Aeroplane Co. Ltd., Filton, at 5.30 p.m.

DERBY BRANCH

4*th November*, 1946—Some Notes for Future Reference, by Dr. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S.

2*nd December*, 1946—Annual General Meeting and Film Show.

The meetings will be held at 6.15 p.m. in the Rolls-Royce Welfare Hall, Nightingale Road, Derby.

HATFIELD BRANCH

Visit.—A visit is to be made to the National Physical Laboratory, Teddington, on Saturday, 23rd November.

LUTON BRANCH

6*th November*, 1946—The Choice of Materials for Aircraft Construction, by Dr. Chalmers.

4*th December*, 1946—Wind Tunnels, by Mr. Hartshorn.

PORTSMOUTH BRANCH

22*nd November*, 1946—Naval Aviation, by Rear-Admiral Sir T. H. Troubridge, K.C.B., D.S.O.

This lecture will be held at 7.0 p.m. in the Central Library Lecture Hall, Portsmouth.

25*th January*, 1947—General Discussion on the Future Prospects of Civil Air Transport, by Sir Frederick Handley-Page, C.B.E., F.R.Ae.S., Sir Harold Hartley (British European Airways), Air Vice-Marshal D. C. T. Bennett (British South American Airways), W. Tye, Esq. (Air Registration Board).

READING AND DISTRICT BRANCH

6th November, 1946—Film Show. Films are kindly being supplied by High Duty Alloys Ltd., showing various aspects of their work, and one of their representatives will be present to answer questions. The film will be given in the Upper Canteen at Miles Aircraft, Woodley; tea will be served from 5.30 p.m., and the film will begin promptly at 6 p.m.

4th December, 1946—Annual General Meeting.

4th January, 1947—Preliminary notice—Dinner Dance.

Evening Classes: At the request of the Branch, the Reading Education Committee has arranged a course of evening classes at the University; initially the course will cover all aspects of aircraft design. The first course will start in the Autumn, 1946, and is not restricted to Branch members, but any of the latter who are interested can obtain details from the Branch Secretary.

SOUTHAMPTON BRANCH

13th November, 1946—Air Transport Operation, by E. Brook Williams, Superintendent of Navigation, B.O.A.C.

11th December, 1946—Naval Aircraft, by A. N. Clifton, M.B.E., B.Sc., F.R.Ae.S.

8th January, 1947—Elementary Metallurgy of Aircraft Materials, by A. Black, M.I.M.

29th January, 1947—Installation of Radio Equipment in Aircraft, by W. T. Davies, A.M.I.E.E.

19th February, 1947—Problems in Fighter Design, by R. L. Lickley, B.Sc., D.I.C., F.R.Ae.S.

All lectures will be held at 7 p.m. in the Physics Lecture Theatre, University College, Southampton.

Election of Members

The following members have been elected recently:—

Associate Fellows

Ernest Fisher Anderson, Michael Gordon Kidston Byrne (from Graduate), Jozef Jan Marian Dziewonski, John Lawrence Fowler, Ellis Vernon Fransman (from Graduate), Stefan Gatowski, Thomas Gibson, Christopher Leonard Sidney Gilford, Maurice Henry Greenacombe, James Hodge (from Graduate), Wilfred Barwell Holroyd (from Associate), Douglas Beresford Hudson, George Ireland (from Student), Cyril John Luby, Bo Klas Oskar Lundberg, Alexander McDonald, Stanley Gordon Marshall (from Graduate), Francis Stransom Nash, Peter Norman (from Graduate), Ivor Howard Rees, Henry Harcourt Ricketts, Frank Henry Robertson (from Associate), Abraham Robinson (from Graduate), Bruce Robinson, John Gordon Ross (from Student), George William Saynor, Alexander Innes Stevenson, Donald Stanley Stewart (from Student), Gerald Wiseman Suggett, Henry Alfred Talbot, Gordon Heatherton Vokes (from Graduate), Alfred Randles Wardle, William Andrews Watts.

Associates

Basil Henry Arkell, William Balloch Batchelor, David Michael Bay, John Laurence Bright, Eric Raymond Bulmer, Archie George Burlingham, Donald Archibald Burn, H.

Busen-Schmitz, John Vipond Campbell, Leslie Frederick Chambers, Digby Vawdre Cotes-Preedy, Alfred Charles Davis, Donald Diamond (from Companion), Alfred Dickinson, Guy Charles Du Merle, George Montagu Eastbury, William Garfield Edwards, Ronald Sidney George Elkin, Sydney George Fisher, George Frederick John Flint, George Thomas Foden, George Henry Ford, James John Leslie Greening, Leo Lewis Hagen, Alfred Holmes Hammond, Joseph Fletcher Harriman, Maurice Walter Hartford, Harry Graham Hastings, Nari Dhun Havely-Walla, Norman James Gunton Hill, Albert John Holloway, Hugh Hull, Patricia Hyde-Edwards, Ernest Thomas Frank Jones, Humphrey Edwards Jones (from Student), Eric Edward Judkins, John Bernard Everett Keeble, George Albert Kennelly, Ronald Stuart Kinsey, Reginald William George Knapp, William Godfrey Ling, Herbert Castle Mason, Robert James Oliver Maybury, Jack Audrey Newton, John Frederick Olver, Henry Ord, Albert Charles Parks, Alec James Morton Peace, Alfred Peters, William Joseph Pullen, Sydney Kenneth Reeves, William Frederick Robinson, Kazimierz Romaniszyn, Geoffrey Claxton Roper, Gilbert Arthur Geoffrey Saywell, Douglas Norman Scard (from Student), Edward Andrew Shipman, Eric Herbert Spouge, Reuben Philip Tanner, Theodore Henry Grant Tasker, Richard Wesley Timms, Leslie Albert Tyrrell, William Henry Warren, Stanley Walter Webb Anthony John Webber, George Leonard Whiley, Edward Ross Hamilton White, John Charles S. White, Russell Littledale Whyham, William Harold Cyril Williams.

Graduates

Arthur Charles Boswell, John Alfred Bridges (from Student), Victor Edward Creighton Brooks (from Student), Norman Ashton Butterworth, Raymond Charles Darroll (from Student), Yashvant Thakorelal Desai (from Student), Norman Bryan Goodsell (from Student), Nigel Gregory, James Anthony Farrer Halls, Gerald John Harris (from Student), John Kenneth Haviland, Derek Joseph Lambert, Kenneth Sumner Lawson, Kenneth John Leighton, James MacKean, Robert Emmanuel Moger, Vernon Dalrymple Naylor, James John Pearson (from Student), Ernest Sidney Roberts, Victor Frow Roberts, Thomas Derek Sills (from Student), Nelson Anthony Simpson (ex-Student), Eric Clive Smith, James William Sprackling, John Stewart Tanner, Stanley Ralph Tyler (from Student), Raymond Hedley Vernon, Kay John Seymour Walker, William Joseph Walker, Dennis Blackwell Wallis (from Student), Ernest Wilks (from Student).

Students

Rupert Christopher Bailey Ashworth, Brian Bastable, Peter Bennison, Bernard Jack Benson, John Blakey, John Michael Bray, David Brown, Julio Bueno, Philip James Castle, William Alfred Caws, Guy Bransby Charter, Albert Cleavely, Reginald Thomas Coleman, Sidney William Arthur Cousins, Anthony Richard Ward Denison, Edward George Downer, Peter Brian Dutton, Geoffrey John Easton, William Alan Fox, Alan Douglas Freeman, Keith Gale, Norman Michael Gemson, David Gill, John Colin Green, Peter Charles Grigg, Kenneth Ronald Guy, Norman Frederick Harpur, Gerald Edward Hoare, John George Kennedy, Albert William Kitchenside, Haydn Sidney Liner, Lawrence Kershaw Lord, Bernard Lovegrove, Kenneth Stanley MacDonald, George Maitland, Donald Lewis Matthews, Joseph Brian Menin, Leslie Stephen Moore, Peter Noyerras Morris, Derek Paul Morriss, John Michael Hubert Ogden, Alfred William Picknell, Robert Arthur Powell, Bernard John Preston, Philip Harold Rance, Rodney George Rose, Robert James Ross, Duncan Menzies Soutar Simpson, Kulbir Singh, Eddie Slap, Ian Hilary Steels, Geoffrey Cowie Sugden, John Sutherland, Gordon Edwin Watkins, David A. Whiffen, Anthony Bradford White, Robert Henry White, John Algar Winter, Leslie Charles Wisdom.

Companions

Gavin Forsyth Anderson, Dirk William Bouwer, Joan Maud Bower, Jan Joseph Bukowsky, Brian Mawson Dodds, Michael Marcus Isaiah Erdman (from Student), Edmund Frank John Gericke (from Student), Charles Frederick Hill, Viscount Knollys, John Peter O'Brien Ledeboer, Charles Bernard Maycock, Thomas William Paddon, Gordon Oscar Singleton, Harold Fred Hammond Smith, James Stanton.

Additions to Library

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

A.a.322.—Elementary Applied Aerodynamics. Paul E. Hemke. Prentice Hall, New York. 1946.

A.a.323.—Les vibrations sur les avions. Maurice Berthaume. Dunod, Paris. 1946.

A.a.324.—Les essais de performances en aeronautique. F. Hussenot. Dunod, Paris. 1946.

A.a.325.—Essais de qualités de vol des avions. Maurice Cambois. Dunod, Paris, 1946.

D.b.259.—Civil Air Transport. W. E. Wynn. Hutchinson. 1946.

D.b.260.—Air Traffic Control. Glen A. Gilbert. Ziff-Davis, New York. No date.

D.c.107.—Airport Planning. C. Froesch and W. Prokosch. Wiley, U.S.A. 1946.

D.f.46.—Aviation Insurance. D. Murray Stewart. Underwriting, Printing and Publishing Co., New York. 1946.

E.c.28.—Prevention of the failure of metals under repeated stress. Bureau of Aeronautics, U.S.A. Chapman & Hall. 1941.

EE.d.11.—Aircraft Carburetion. R. H. Thorner. Wiley, U.S.A. 1946.

G.a.76.—Airframe Materials. F. S. Stewart. McGraw Hill, New York. 1945.

U.h.3.—Atti di Guidonia. Volumes I-IV. Direzione Studi ed Esperienze del Ministero dell'Aeronautica.

**L.d.115.—*Notices to Airmen.* Nos. 152-167 inclusive. *Ministry of Civil Aviation.* 1945-46.

German War-time Research in Physics. Abstracts compiled by S.I.G.E.S.O. Supplement No. 2, August, 1946.

***Commonwealth of Australia C.S.I.R. Division of Aeronautics. Report S.M.52. Strength testing of aircraft wings, a review of current methods. W. W. Johnstone. C.S.I.R. Australia.* 1946.

National Advisory Committee for Aeronautics, U.S.A.

***N.A.C.A. Technical Notes:—*

1013.—*Stresses in and general instability of monocoque cylinders without cutouts. I. Experimental investigation of cylinders with a symmetric cutout subjected to pure bending. N. J. Hoff and B. A. Boley.*

1014.—*Stresses in and general instability of monocoque cylinders with cutouts. II. Calculations of the stresses in a cylinder with a symmetric cutout.*

1040.—*Wake studies of eight model propellers. E. G. Reid.*

1041.—*Effect of normal pressure on strength of axially loaded sheet stringer panels. A. E. McPherson, S. Levy and George Zibritosky.*

1057.—*General tank tests of a* 1/10 *size model of the hull of the Boeing XPBB-I flying boat Langley tank model* 175. *D. A. King and Mary B. Hill.*

1059.—*Effects of tip dihedral on lateral stability and control characteristics as determined by tests of a dynamic model in the Langley free-flight. H. O. Ankenbruck.*

1070.—*An empirical equation for the coefficient of heat transfer to a flat surface from a plane heated air jet directed tangentially to the surface. John Zerbe and James Selna.*

1076.—*A simplified method for determining from flight data the rate of change of yawing moment coefficient with side slip. R. C. Bishop Harvard Lomax.*

1077.—*Jet boundary and plan form corrections for partial span models with reflection plane end plate, or no end plate in a circular closed wind tunnel. J C. Sivells and O. J. Deters.*

1082.—*Comparative effectiveness of a conviction-type and a radiation-type cooling cap on a turbosupercharger. F. J. Hartwig.*

1085.—*Flight tests of experiment* 1 *beveled-trailing-edge frise ailerons on a fighter airplane. Fabian Goranson.*

1086.—*Thermodynamic charts for the computation of combustion and mixture temperatures at constant pressure. L. R. Turner and A. M. Lord.*

1087.—*Langley full scale tunnel investigation of the fuselage boundary layer on a typical fighter airplane with a single liquid cooled engine. K. A. Czarnecki and Jerome Pasamanick.*

1088.—*Influence of large amounts of wing sweep on stability and control problems of aircraft. Hartley A. Soule.*

1090.—*The shearing rigidity of curved panels under compression. N. J. Hoff and B. A. Boley.*

1094.—*Experimental determination of the effects of dihedral vertical tail area, and lift coefficient on lateral stability and control characteristics. Marion McKinney.*

1099.—*Two-dimensional wind tunnel investigation of sealed* 0.22 *airfoil chord internally balanced ailerons of different contour on an N.A.C.A.*65 (112) 213 *airfoil. A. L. Braslow.*

1102.—*The crystal structure at room temperature of eight forged heat-resisting alloys. J. H. Kittel.*

1103.—*The langrangian multiplier method of finding upper and lower limits to critical stresses of clamped plates. B. Budiansky and Pai C. Hu.*

1104.—*Experimental determination of the effects of directional stability and rotary damping in yaw on lateral stability and control characteristics. H. M. Drake.*

1106.—*Performance parameters for jet propulsion engines. N. D. Sanders.*

1108.—*Loading capacity of aluminium alloy crankpin bearings as determined in a centrifugal bearing test machine. E. F. Macks and M. C. Shaw.*

1111.—*Investigation of the effect of a tip modification and thermal de-icing air flow on propeller performance. B. W. Corson and J. D. Maynard.*

1112.—*Analysis of propeller efficiency losses associated with heated air thermal de-icing. B. W. Corson and J. D. Maynard.*

1117.—*Comparison of relative sensitivities of the knock limits of two fuels to six-engined variables. H. A. Cook, L. F. Held and E. I. Pritchard.*

1118.—*Effect of compressibility at high subsonic velocities on the lifting force acting on an elliptic cylinder. Carl Raplan.*

**A.R.C. Reports and Memoranda:—

1921.—*Measurement of pitching movement derivatives for an aerofoil oscillating about the half chord axis.* J. B. Bratt and C. Scruton.

1942.—*Flexure-torsion flutter derivatives for semi-rigid wings.* R. A. Frazer.

1990.—*Methods of predicting flexure-torsion flutter of cantilever wings.* J. Williams.

1993.—*The effect of openings on the torsional stiffness of rectangular section tubes.* H. J. Allwright.

1996.—*The approximate calculation of the lift of symmetrical aerofoils taking account of the layer, with application to control problems.* J. H. Preston.

2001.—*The supersonic theory of wings of finite span.* M. J. Lighthill.

2003.—*Supersonic flow past bodies of revolution.* M. J. Lighthill.

2014.—*Experiment on the measurement of transition position by chemical methods.* J. H. Preston, N. E. Sweeting and F. H. Burstall.

2018.—*Experiments on a model Falcon aeroplane with wings of standard and high taper.* H. B. Irving, A. S. Batson, J. H. Warsap and H. J. Gummer.

2034.—*The prevention of flutter of spring tabs.* A. R. Collar.

2036.—*High speed lift and drag data for propeller performance calculations.* A. B. Haines and R. J. Monaghan.

2042. *Compression tests on seven panels of monocoque construction.* H. L. Cox, F. R. Thurston and E. P. Coleman.

2043.—*Integrating coefficients for airscrew analysis.* C. N. H. Lock and A. E. Knowles.

2047.—*The elimination of flutter from a propeller.* L. H. G. Sterne.

2055.—*Compressibility increase of lift and moment on ECI250 for low speed Cl.*0.17. J. A. Beavan and G. A. M. Hyde.

2057.—*Subsonic and supersonic high speed tunnel tests of a faired double wedged aerofoil.* W. F. Hilton and F. W. Pruden.

2060.—*The effect of fuselage and nacelles on wing bending moment shear and torsion.*

2061.—*Tests of the effect of wing tip section on stalling properties of a low-wing monoplane. Part I. Low taper wings (Falcon).* G. E. Pringle and R. H. Francis. *Part II. High taper wing with N.A.C.A.*4415 *tip.* R. H. Francis and A. W. G. Birch.

2062.—*The influence of remote and flexible mass-balance arms on elevator flutter:— Part I. Elevator mass-balance in relation to flexibility of the arm and position of the fuselage nodal point.* D. Williams. *Part II. Experiments on the influence on symmetrical elevator flutter of remote mass-balance arm systems with various flexibilities and gear ratios.* C. Scruton and W. G. Raymer.

2072.—*Strain gauge test of a fluttering propeller in a wind tunnel.* F. Clifton and L. H. G. Stone.

British Intelligence Objectives Sub-Committee:—

F.I.A.T. Final Report No. 237,238.

F.I.A.T. Final Report No. 612.

F.I.A.T. Final Report No. 624.

F.I.A.T. Final Report No. 802.

British Intelligence Objectives Sub-Committee:—

B.I.O.S. Final Report No. 171. *Item No.* 22.
B.I.O.S. Final Report No. 603. *Item No.* 9.
B.I.O.S. Final Report No. 381. *Item Nos.* 18, 19 *and* 26.

J. LAURENCE PRITCHARD,
Secretary.

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TECHNOLOGY DEPT.

THE ROYAL AERONAUTICAL SOCIETY

4 HAMILTON PLACE, PICCADILLY, LONDON, W.1

DECEMBER NOTICES 1946

JOURNAL PREMIUM AWARDS

The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.

Contents of December Journal

A Critical Review of German Research on High-Speed Airflow, by R. Smelt, M.A., A.F.R.Ae.S.

The Problems of Blind Landing, by H. C. Pritchard, B.A., A.F.R.Ae.S.

The Separation of Principal Stresses in Photo-Elastic Analysis, by E. K. Frankl, M.A.

A Review of Recent Progress in Aircraft Gun Design as it Affects Installation in Aircraft, by G. F. Wallace, A.F.R.Ae.S.

Correspondence.

Index to Vol. L.

Christmas Holidays

The offices of the Society will be closed from 5 p.m. Tuesday, 24th December, until 9.30 a.m. Monday, 30th December.

The Geoffrey de Havilland Memorial Fund

A fund is being raised to provide an annual aeronautical research scholarship in memory of Geoffrey de Havilland. The detailed conditions of the award of the scholarship are still under consideration. The fund will be administered by the Royal Aeronautical Society. It is hoped to raise a capital sum of at least £5,000 and any contributions should be sent either to the Geoffrey de Havilland Memorial Fund, Barclays Bank, Burnt Oak, Edgware, or the Secretary, Royal Aeronautical Society. Cheques should be made out to the Geoffrey de Havilland Memorial Fund.

Council Meeting

A meeting of Council was held on Thursday, 31st October, 1946, at which the following were present:—

Sir Frederick Handley Page (President) in the Chair; Lord Brabazon of Tara; Sir John Buchanan; Major G. P. Bulman; Mr. S. Camm; Mr. G. P. Douglas; Mr. A. G. Elliott; Sir A. H. Roy Fedden (Past President); Mr. A. Gouge (Past President); Mr. E. T. Jones; Sir Ben Lockspeiser; Mr. P. G. Masefield; Major R. H. Mayo; Mr. W. G. A. Perring; Mr. N. E. Rowe; Dr. H. Roxbee Cox (Vice-President); Captain C. F. Uwins.

Among the business transacted was the following:—

The Council agreed to administer the fund being raised for the award of a scholarship in memory of Geoffrey de Havilland. The President was nominated as the Society's official

delegate to the centenary celebrations of the Institution of Mechanical Engineers which will be held in June, 1947. The recommendations of the Grading Committee for election to Associate Fellowship and other grades in the Society were passed. The Council considered reports from the General Purposes Committee, the Technical Committee, the Finance Committee, the Lectures Committee and the Journal Committee.

Meetings at the Headquarters of the Society

During the past month meetings have been held at the offices of the Society, 4 Hamilton Place, by the following organisations:—

Aerodrome Owners Association.
Aeronautical Research Committee (on various occasions).
Air Charter Corporation.
Aircraft Recognition Society.
British Standards Institution.
Guild of Air Pilots and Air Navigators.
Light Aeroplane Clubs.
Society of British Aircraft Constructors.

Annual Subscriptions of Members

Members are reminded that their subscriptions become due on January 1st, 1947.

The present subscriptions are:—

	Home. £ s. d.	Abroad. £ s. d.		Home. £ s. d.	Abroad. £ s. d.
Founder Members ..	2 2 0	2 2 0	Graduates (age 21-25)	2 2 0	2 2 0
Fellows	4 4 0	3 3 0	Graduates (age 26-28)	2 12 6	2 12 6
Associate Fellows ..	3 3 0	2 2 0	Students	1 1 0	1 1 0
Associates	2 2 0*	2 2 0*	Companions ..	2 2 0	2 2 0

* £1 1s. 0d. without Journal.

Journal Binding

Owing to increased costs, the prices of binding of Journals will be as follows:—

1946 Volume 12/6.
Previous Volumes 13/6.

Journals should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the office of the Society.

Changes of Address

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
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The following are the forthcoming lectures for the Autumn Session, 1946. Members are admitted without tickets, but non-members must obtain tickets through a member.

The lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1 (by permission of the Council of the Institution). Tea will be served at 5.30 except where otherwise stated.

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19th December, 1946—The Evolution of the Spitfire, by Mr. J. Smith, C.B.E., F.R.Ae.S.

Graduates' and Students' Section

Friday, 10th January, 1947—Dance at the Paviours Arms, Page Street, Westminster. Tickets, price 4/6 single, 8/- double, may be obtained from the Hon. Secretary, J. G. Roxburgh, 62 Fitzjohn's Avenue, London, N.W.3, or from the local Section Representative.

Branch Lectures and Notices

BELFAST BRANCH

10th December, 1946—Wind Tunnels, by Mr. J. A. Kirk.

7th January, 1947—Gliding, by Professor G. T. R. Hill, F.R.Ae.S.

24th January, 1947—Smoking concert.

11th February, 1947—Electrics in Aircraft, by Mr. Woodford, A.F.R.Ae.S.

11th March, 1947—Gas Turbines and Jets, by Mr. J. Hodge, A.F.R.Ae.S.

All lectures will be held in the Central Hall, Belfast College of Technology.

BIRMINGHAM BRANCH

19th December, 1946—Pneumatics for Aircraft and the Aircraft Industry, arranged by Hymatic Engineering Co. Ltd., at Birmingham Chamber of Commerce, 7 p.m.

BRISTOL BRANCH

10th December, 1946—Some Notes for Future Reference, by Dr. Roxbee Cox, Ph.D., D.I.C., B.Sc., F.R.Ae.S.

(This lecture will be held at 6.30 p.m. in the large lecture hall of the Merchant Venturers Technical College and will be followed by a buffet supper.)

7th January, 1947—Brains Trust, with Captain J. Laurence Pritchard, Hon.F.R.Ae.S., as Question Master.

28th January, 1947—Large Aircraft, by A. E. Russell, Esq., B.Sc., F.R.Ae.S., Chief Engineer, Bristol Aeroplane Co. Ltd., Aircraft Division.

18th February, 1947—Radar—Its Uses and Possibilities in Civil Aviation, by F. R. Willis, Esq., B.Sc., A.M.I.E.E., A.F.R.Ae.S., Radio Development Section, B.O.A.C.

4th March, 1947 Some Aspects of Stability and Control, by Prof. A. R. Collar, M.A., B.Sc., F.R.Ae.S., Professor of Aeronautical Engineering, University of Bristol.

25th March, 1947—Competition for the best paper read by a Junior Member.

15th April, 1947—Annual general meeting and film show.

All meetings, except that of 10th December 1946, will be held in the Conference Room, Filton House, Bristol Aeroplane Co. Ltd., Filton, at 5.30 p.m.

DERBY BRANCH

2nd December, 1946—Annual General Meeting and Film Show. At 6.15 p.m. in the Rolls-Royce Welfare Hall, Nightingale Road, Derby.

GLASGOW BRANCH

14th December, 1946—Annual General Meeting. At 2.30 p.m. at the Central Hotel.

GLOUCESTER AND CHELTENHAM BRANCH

13th December, 1946—Gas Turbine and Jets, by Mr. J. Hodge, A.F.R.Ae.S. At the Canteen, Gloster Aircraft Co., Ltd., Hucclecote, at 7.30 p.m.

10th January, 1947—Liquid Springing, by Mr. R. H. Bound, F.R.Ae.S. At Dowty Equipment, Ltd., Arle Court, Cheltenham, at 7.30 p.m.

HATFIELD BRANCH

13th December, 1946—Annual Dance.

LUTON BRANCH

4th December, 1946—Wind Tunnels, by Mr. Hartshorn.

PORTSMOUTH BRANCH

24th January, 1947—General Discussion on the Future Prospects of Civil Air Transport, by Sir Frederick Handley-Page, C.B.E., F.R.Ae.S., Sir Harold Hartley (British European Airways), Air Vice-Marshal D. C. T. Bennett, F.R.Ae.S. (British South American Airways), W. Tye, Esq., A.F.R.Ae.S. (Air Registration Board).

READING AND DISTRICT BRANCH

4th December, 1946—Annual General Meeting.

4th January, 1947—Dinner Dance.

Evening Classes: At the request of the Branch, the Reading Education Committee has arranged a course of evening classes at the University; initially the course will cover all aspects of aircraft design. The first course will start in the Autumn, 1946, and is not restricted to Branch members, but any of the latter who are interested can obtain details from the Branch Secretary.

SOUTHAMPTON BRANCH

11th December, 1946—Naval Aircraft, by A. N. Clifton, M.B.E., B.Sc., F.R.Ae.S.

8th January, 1947—Elementary Metallurgy of Aircraft Materials, by A. Black, M.I.M.

29th January, 1947—Installation of Radio Equipment in Aircraft, by W. T. Davies, A.M.I.E.E.

19th February, 1947—Problems in Fighter Design, by R. L. Lickley, B.Sc., D.I.C., F.R.Ae.S.

All lectures will be held at 7 p.m. in the Physics Lecture Theatre, University College, Southampton.

Election of Members

The following members have been elected recently:—

Associate Fellows

Stanley Ernest Beddall, Kenneth Glenny Bergin, Cyril Forrester Bethwaite, Samuel James Gordon Black, John Springfield Boulton, Tadeusz Leopold Ciastula, John Fearn, William Henry Noel Gibby (from Graduate), Alfred Norman Irens, Joseph Lambert Jameson, David William Jones (from Graduate), Harischandra Kashinath Karve (from Associate), Raymond Henry Kewish, Leo Barnum Kimball, Francis Nicolas Kirk (from Graduate), Richard Francis Lloyd Jones, Harry Alan Marsh (from Associate), Herbert Austin Mather (from Graduate), Alfred Dennis Miller, Dahlke Migara Ratnatunga (from Associate), Reginald William Lemon Reed, Kenneth Ritchley, Walter Rogers, Paul Torda (from Associate), Alban Joseph Walsh (from Associate), William Walter Warner, John Robert Webber, George William Wilson (from Associate).

Associates

Dennis Harry Clarke (from Student), Stafford Coates, Ambrose Leo Cresswell, Leslie Wyndham Crum (from Student), Laurence Archibald William Deane, Edward Morton Drummond, William Henry Else, Robert John Greenshields, Gilbert Ratcliffe Hadfield, Cyril Henry Harvey, Albert Teichmann Howell, Robert Caddle Hunter, Frederick Henry Jones, Albert George Knivett, George Sutton Lace, Denys Mervyn Lambert, Harry Wilson Luty, Ronald Thomas Mann, Frederick William Morgan, Ralph Silvanus Munday, Eric Thomas Orringe, Eric George Parramore, Arthur Ernest Polden, William Edward Reynolds, William Charles Stanley Roberts, Kenneth Gordon Wallace, Dudley Frank Walker, John Henry Walmsley (from Student), Bernard Webster, Leslie William Wood.

Graduates

Robert Angles, Frank Wallace Austin, Owen Richard Ballard (from Student), Albert Frank Barnes, Rodney Wellington Dundock, Mervyn Reginald Dart, William Marshall Dunn, Hugh Haslett Eccles, William Ronald Farr (from Student), Philip Murray Franz (from Student), Alexandre Henry Frick (from Student), Robert John Griggs (from Student), John Maxwell Hands (from Student), Norman George Hatton, Maurice Henry Albert Kempster, Leslie Robert Knight, Warner Lennard Kuttner, John William Langworthy, Gordon Manns Lewis, Alan Bycroft Lowe, Brian Phillip McLaughlin, Frederick Arthur Parsons, John Bernard Partridge (from Student), Geoffrey Alan Peacock, Harry Rewitch (from Student), Arthur Rodgers, Walter Richard Shapey, Peter Henry Southwell (from Student), Robert Henry Stevens (from Student), Sidney Tyes, Edward Leith Way, Lloyd Williamson, Peter Frank Witherden.

Students

Arthur Derwent Chapman, Lewis Frederick Crabtree, Hugh Oliver Ewart, Thomas Cyril Greaves, David Neill Harrison, Paul Alexander Hilton, Donald Howard, Philip Jarvis Johnson, Edward Geoffrey Lewis, Guy Anthony Maakad, John Geoffrey Male, Derrick George Murkett, Peter Ivor Douglas O'Brien, Phyllis Doreen Palmer, Desmond Park, Singh Mehta Rai, Geoffrey Daniel Rawkins, Dennis Frederick Saunders, Geoffrey Cuthbert Scott, John Denman Sibley, Ronald Maurice Siely, George Tolmie Skinner, Alan Stanbrook, Frank Melvin Stansfield, Alan Hugh Stenning, John Brian Turtle, John Malcolm Williams.

Companions

William Gould Carter, John Spencer Rivaz.

Acknowledgments

The Council acknowledge with grateful thanks the gift of photographs from Mr. Marcus Langley, Fellow.

Additions to the Library

Pamphlets in italics with location reference following in brackets. Books marked * or ** may not be taken out on loan.

A.a.326.—Physics of Flight. Alfred Landé. Reinhold Publishing Co., New York. 1945.

A.a.327.—Aerodynamics. A. Wiley Sherwood. McGraw Hill. 1946.

B.c.71.—Gyroscope and its Application. Martin Davidson (ed.). Hutchinson. 1946.

E.h.28.—Factory Layout, Planning and Progress. W. J. Hiscock. Pitman. n.d.

EE.f.51.—Maintenance of High-Speed Diesel Engines. 3rd edition revised. A. W. Judge. Chapman & Hall. 1946.

G.a.77.—Metallurgical Abstracts. Volume 12. N. B. Vaughan (ed.). Institute of Metals. 1945.

K.c.25.—Dawn of the Space Age. Harry Harper. Sampson Low. 1946.

L.d.115.—*Notices to Airmen*. No. 165, 166, 167, 168, 169, 170, 171, 172, 173, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184.

S.a.146.—Camouflage 1939-42. Aircraft. O. G. Thetford. Harborough Publishing Co. 1946.

S.b.149.—Task for Coastal Command. Hector Bolitho. Hutchinson. 1944.

S.b.150.—*There's Freedom in the Air*. Air Ministry. H.M.S.O. 1944.

S.b.151.—Spitfire. J. W. R. Taylor and M. F. Allwood. Harborough Publishing Co. 1946.

UB.5.—*F.I.A.T. Final Report No.* 81. *Centrifugal casting of metals in Germany. B.I.O.S. H.M.S.O.* 1946.

UB.5.—*F.I.A.T. Final Report No.* 625. *Spur gear high pressure pumps designed by Egerdöerfer. B.I.O.S. H.M.S.O.* 1946.

UB.5.—*F.I.A.T. Final Report No.* 581. *Beier infinitely variable speed friction drive transmission. B.I.O.S. H.M.S.O.* 1946.

UB.5.—*F.I.A.T. Final Report No.* 288. *Rural telephone service, dial switching for telewriter systems, and miscellaneous items. B.I.O.S. H.M.S.O.* 1946.

UB.5.—*B.I.O.S. Final Report No.* 757. *Item No.* 22. *Manufacture of Ethylene Cyanhydrin at I.G. Ludwigshafen. H.M.S.O.* 1946.

UB.5.—*B.I.O.S. Final Report No.* 409. *Item No.* 27. *D.C. cup type motors by Siemens Schuckert Zaehlerwerk, Nürnberg. H.M.S.O.* 1946.

UB.7.—*Effect of valve overlap on detonation performance. K. W. Nobbs and M. O'Farrell. Thornton Laboratory.* 1946.

UB.7.—*Gas turbine combustion studies—gas analysis. R. R. Baldwin. Thornton Laboratory.* 1946.

UC.4.—*ACA* 19. *Review of hot wire anemometry. J. B. Willis. Australian Council for Aeronautics.* 1946.

UC.4.—*ACA* 20. *Some mathematical aspects of compressible flow. R. H. Dalitz. Australian Council for Aeronautics.* 1946.

UC.4.—*ACA* 21. *Investigations on Bellowe flaps. F. W. David and I. H. Ring. Australian Council for Aeronautics.* 1946.

UC.5.—*C.S.I.R. Australia. SM* 72. *Theory of the Bourdon tube. Elizabeth H. Mann. C.S.I.R. Division of Aeronautics.*

UF.—*Les cahiers d'Aerodynamiques. No.* 5. *Chaire d'aviation de la Sorbonne. University of Paris.* 1946.

WB.15.—*Journal of the Institute of Metals. Vol.* 71. *N. B. Vaughan (ed.). Institute of Metals.* 1945.

A.R.C. Reports and Memoranda.

2023.—*An improved smoke generator for use in the visualisation of airflow, particularly boundary layer flow at high Reynolds numbers. J. H. Preston and N. E. Sweeting.*

2019.—*Model experiments on the rolling moment due to sideslip of tapered wing monoplanes. H. B. Irving, A. S. Batson and J. H. Warsap.*

2037.—*Some preliminary measurements of the boundary layer conditions on models in the R.A.E. seaplane tanks. G. L. Fletcher.*

2045.—*The critical flow conditions of a gas in a convergent passage and the influence of frictional losses. S. J. Moyes.*

2053.—*Note on methods of determining transition on an aerofoil in a wind tunnel. E. J. Richards and T. W. Brown.*

2056.—*Examples of pressure distributions at compressibility speeds on EC* 1250. *J. A. Beavan and G. A. M. Hyde.*

Publications Scientifiques et Techniques du Ministère de l'Air. Bulletin des Services Techniques. No. 108. Théorie des compas magnétiques et des indicateurs de cap utilisés en aviation. Guy Robert. 1946.

J. LAURENCE PRITCHARD.
Secretary.

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